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Developing a resilient green cellular network

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NAVAL POSTGRADUATE SCHOOL

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THESIS

DEVELOPING A RESILIENT GREEN CELLULAR NETWORK

by

Roger Sankerdial

December 2013

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13. ABSTRACT (maximum 200 words)

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The purpose of this research is to direct attention to the importance of cellular base station functionality during power outages and illustrate how these assets require modification to provide critical communications for the public to summon aid, and first responders to coordinate response efforts. Prior research offers strategies to implement post-disaster remediation supplanting failed localized communication infrastructure. This mitigating strategy requires substantial time, labor, and planning to deploy that subsequently detracts from conducting immediate response and recovery. This research is intended to propose a path forward for resiliency in U.S. mobile cellular networks using renewable/alternative energy outlined in India's National Telecom Policy for 2012.

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DEVELOPING A RESILIENT GREEN CELLULAR NETWORK

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As technology drives society to a ubiquitously wireless world, the paradox of mobile wireless network accessibility versus resilience is disturbingly trending in opposite directions. The demand for cellular networks with greater capacity and bandwidth appears to be the primary factor in expanding coverage nationwide, with resilience becoming a secondary thought. It is expected that resilient systems will be able to withstand shocks and stresses from critical incidents and still be able to function as intentionally designed. However, the fragility of cellular networks affected by recent disasters within the last ten years has demonstrated otherwise.

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LIST OF ACRONYMS AND ABBREVIATIONS

4G-LTE	4th Generation Long-Term Evolution
BS	Baser Stations, Cell Sites, Cell Towers
COs	Telecom Central Office
COW	Cellular on Wheels
DHS	Department of Homeland Security
FCC	Federal Communications Commission
FirstNet	First Responder Network Authority
GDP	Gross Domestic Product
IP	Internet Protocol
MHZ	Megahertz
MTSO	Mobile Telephone Switching Office
NPSBN	National Public Safety Broadband Network
NTIA	National Telecommunications and Information Administration
NTP/NTP-2012	India’s National Telecommunications Policy for 2012
PV	Photovoltaic
RF	Radio Frequency
RGGI	Regional Greenhouse Gas Initiative
SOC	Self Organized Criticality

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EXECUTIVE SUMMARY

Modern telecommunication systems are expected by the public to provide reliable service—most importantly during critical situations allowing the public to summon help while first responders simultaneously coordinate rescue and recovery efforts. Given recent telecom failures seen throughout the U.S. within the last ten years attributed to natural disasters, a problematic paradox appears to present itself. There are various causes for system failure, but the most prominent is the loss of commercial grid power. However, apparent this may be, there still exists a lack of collaboration between government and private telecom entities to remedy this issue.

Considering the global proliferation and dependence of mobile devices and applications, along with the parallel demand for wireless infrastructure these devices operate over, it is startling that cellular phone carriers are not required nor are proactively installing backup power to cell tower base stations. Base stations provide wireless access for mobile phones and devices to the wired telephone network. Without base stations (BSs) being operational, the public and private sector that are dependent on cellular devices become incapable of transmitting voice or data; hence, communications blackout for those without access to landline phones.

The importance of BS functionality during power outages becomes a critical issue the National Public Safety Broadband Network will need to consider. This public safety network is proposed to provide interoperable communications between first responder through out the country and would rely heavily on some aspect of commercial BSs. In order to expand on this premise, the telecommunications infrastructure supporting mobile cellular access has been analyzed within this research, with an emphasis placed on base stations also referred to as cell sites. Changes are required to the commercial cellular network in order to provide the National Public Safety Broadband Network mission critical capacity for first responders during emergency incidents.

India's National Telecommunications Policy for 2012 offers potential solutions to provide BS autonomy from grid power through alternative energy, such as: fuel cells and

renewable photovoltaic (PV), wind energy, reducing fossil fuel dependency while lowering harmful carbon emissions. This strategy provides prospective implications throughout the globe with conceivable application for the U.S., as noted in *Scientific America*, January 2013, "Even in developed nations with reliable electricity, changes in the structure of mobile networks could open the door for alternative energy."[1]

1 Katherine Tweed, "Why Cellular Towers in Developing Nations are Making the Move to Solar Power," *Scientific American* (January 15, 2013).

I. DEVELOPING A RESILIENT "GREEN" CELLULAR NETWORK

A. INTRODUCTION

An examination of the commercial wireless industry reveals a strategy of vast reaching national coverage, in anticipation of the trajectory of mobile cellular demand. *CTIA The Wireless Association*, an international nonprofit trade association representing major wireless carriers, reports there were approximately 213,299 cell sites nationwide in the U.S. as of December 2007. That figure five years later had risen to 301,779, an astonishing 41 percent increase.[1] The global economy has developed an insatiable need for wireless infrastructure in order to support the massive growth of mobile commerce (m-commerce) generated via mobile devices, with retail sales projected to reach $86.86 billion in the U.S. by 2016.[2] Reflecting this reality, *Presidential Memorandum* dated June 2010 states, "the world is going wireless, and we must not fall behind."[3] The demand for mobile cellular access has prompted many households in the U.S. to forego wired phone connectivity. One in three households (34 percent) in the U.S. have transitioned to cell phones as their primary telephone service, opting out of conventional landline service as reported by the National Center for Health Statistic, June 2012.[4]

Many consumers have grown accustomed, though, to the reliability of copper landlines during power outages. An article produced by Consumer Reports, January 2012 titled, "Surprise! Your High-Tech Home Phone System Could Go Dead in An Emergency" explains how unlike fiber, copper bears inherent properties capable of withstanding local power outages for at least a certain period of time. "The benefit of the

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1 "Wireless Quick Facts," http://www.ctia.org/advocacy/research/index.cfm/AID/10323, Comparison taken from December 2007 to December 2012.

2 "eMarketer: Tablets, Smartphones Drives Mobile Commerce to Record Heights." www.eMarketer.com.

3 President Barack Obama, "Presidential Memorandum: Unleashing the Wireless Broadband Revolution," The White House, Office of the Press Secretary, http://www.whitehouse.gov/the-press-office/presidential-memorandum-unleashing-wireless-broadband-revolution.

4 Stephen J. Blumberg, Julian V. Luke, Nadarajasundaram Ganesh, Michael E. Davern, and Michel H. Boudreaux, *National Health Statistics Reports Number 61*, U.S. Department of Health and Human Services, October 12, 2012.

old copper service is that, unlike fiber…it carries not only the voice and data signals but also the power to operate a standard, noncordless telephone."[5] Phone companies are hoping to decommission landlines for an all-digital network, providing high-speed connectivity— but with a critical dependency on commercial grid power. Both AT&T and Verizon, the largest U.S. telecom service providers have requested approval from the federal government to proceed with upgrading their telecom network infrastructure to support phone service with Internet-technology traversing over airwaves and fiber.[6] Many consumers, however, do not realize the intrinsic weakness of this proposal as noted in Verizon's "Terms of Service for FiOS Digital Voice", which states, "The Service (including 911 dialing) will not function during a power outage without a back-up power source."[7]

Modern telecommunication systems are expected by the public to provide reliable service—most importantly during critical situations allowing the public to summon help while first responders simultaneously coordinate rescue and recovery efforts. Given recent telecom failures seen throughout the U.S. within the last ten years attributed to natural disasters, a problematic paradox appears to present itself. There are various causes for system failure, but the most prominent is the loss of commercial grid power. However, apparent this may be, there still exists a lack of collaboration between government and private telecom entities to remedy this issue. There are a host of reasons that prevent productive dialogue. The most prevalent appears to gravitate around the cost associated in upgrading this wireless infrastructure.

Considering the global proliferation and dependence of mobile devices and applications, along with the parallel demand for wireless infrastructure these devices operate over, it is startling that cellular phone carriers are not required nor are proactively

5 "Surprise! Your High-Tech Home Phone System Could Go Dead in an Emergency," ConsumerReports.org, http://www.consumerreports.org/cro/2012/01/surprise-your-high-tech-home-phone-system-could-go-dead-in-an-emergency/index.htm.

6 Scott Moritz and Todd Shields, "Fire Island Becomes Test Case as Verizon Abandons Copper," *Bloomberg*, http://www.bloomberg.com/news/201300-700-8/fire-island-becomes-a-test-case-as-verizon-abandons-copper-tech.html.

7 "Verizon FiOS Digital Voice Terms of Service; Section 2 B," http://www36.verizon.com/fiosvoice/terms/Terms_of_Service.pdf.

installing backup power to cell tower base stations. Base stations (BS) provide wireless access for mobile phones and devices to the wired telephone network. Without BSs being operational, the public and private sector that are dependent on cellular devices become incapable of transmitting voice or data; hence communications blackout for those without access to landline phones.

BSs are predominantly mounted on fixed structures high above the landscape, allowing the broadcasting of radio frequency (RF) to travel for several miles. Most BSs rely on commercial grid power to operate. When power is lost, they cease to function, unless equipped with some form of backup power, which can be provided by various sources—the most common being battery banks. Considering the strategic direction of the two largest telecom providers in the U.S. migrating to an all digital network operating of BSs and fiber, it can logically be inferred that BSs should be resilient, capable of withstanding shocks and stresses from critical incidents while still being able to function as intentionally designed.[8] However, the fragility of cellular networks affected by the litany of major disasters, have demonstrated otherwise.

There has been much debate over the U.S. commercial cellular network and the lack of resilience and how that adversely affects first responders and the public during natural and man-made disasters.[9] The fragility of this cellular infrastructure requires modification, as the National Public Safety Broadband Network (NPSBN) has received legislative approval. The NPSBN is proposed to provide interoperable communications between first responders throughout the country through a singular standardized system. It is anticipated to leverage a great capacity of commercial cellular BSs. The Federal Communications Commission (FCC) has conducted inquiries into keeping this network functioning during major calamities and natural disasters.[10] A failure to address the intrinsic weakness of the US commercial cellular network exponentially increases the

8 Judith Rodin and Felix Rohatyn Lazard, Co-Chairs. *NYS 2100 Commission Recommendations to Improve the Strength and Resilience of the Empire State's Infrastructure*, 2013.

9 L. K. Moore, *The First Responder's Network and Next-Generation Communications for Public Safety: Issues for Congress,* CRS Report 42543 (Washington, DC: Library of Congress, Research Service, March 5, 2013).

10 "Surprise! Your High-Tech Home Phone System Could Go Dead in an Emergency."

risk of first responders and the US populace being able to communicate during power outages. The NPSBN is currently in a conceptual stage with requirements codified in the *Middle Class Tax Relief and Job Creation Act of 2012*. The First Responder Network Authority (FirstNet) will bear the immense responsibility of overseeing the development of the NPSBN over the next ten years.

Achieving a robust and resilient cellular network requires a long-term investment and strategy that limits the effects of outages caused by the loss of grid power. The U.S. can look to nations that encounter frequent power outages for potential solutions to off set such dependency. India, the second largest mobile phone market globally recognized the potential value of mobile commerce and proactively strategized investing in the expansion and reliability of their cellular network, as noted in their National Telecom Policy-2012 (NTP).[11] The policy posits how India can achieve its economic potential while providing socio-economic parity to its under serviced rural areas through a self-sustainable "Green" cellular network capable of operating without grid power. This demographic represents the majority population and plays a substantial role in stimulating future commerce. The strategy addresses a key impediment throughout the country—an unreliable and underdeveloped commercial power grid. The core premise within the NTP is to transition the nation away from a diesel dependent cellular network and to one that employs environmentally friendly and sustainable renewable/alternative energy.

Various studies have emerged offering potential solutions to provide BS autonomy from grid power through alternative energy, such as: fuel cells and renewable photovoltaic (PV), wind energy, reducing fossil fuel dependency while lowering harmful carbon emissions. This strategy provides prospective implications throughout the globe with conceivable application for the U.S., as noted by Katherine Tweed, "Even in developed nations with reliable electricity, changes in the structure of mobile networks could open the door for alternative energy."[12]

[11] *India's National Telecom Policy - 2012* Government of India, Ministry of Communications & IT, Department of Telecommunications, June 2012.

[12] Tweed, "Why Cellular Towers in Developing Nations are Making the Move to Solar Power."

In order to expand on this premise, the telecommunications infrastructure supporting mobile cellular access has been analyzed within this research, with an emphasis placed on base stations also referred to as cell sites or cell towers.

B. PROBLEM STATEMENT

The growth of smart phones, tablets, PCs, mobile Wi-Fi cards, and e-readers has increased the demand on mobile cellular networks. Sales of smart phones in 2012 are listed at 712.6 million, translating to an increase of 44.1 percent from 2011, reported by the International Data Corporation.[13] As these devices grow in usage, so does the consumption of finite bandwidth—resulting in a technological shift to compensate and optimize to meet this exponential demand. In doing so, the telecom wireless industry travels down a path that Per Bak describes as Self Organized Criticality (SOC), which "increases because of incremental, but continuous, optimizations and other expediencies designed to improve daily life."[14] These wireless networks, at stretched capacity, develop vulnerabilities from a lack of diversity, making them brittle, and inevitably at higher risk of catastrophic failures.[15]

As technology drives society to a ubiquitously wireless world, the paradox of mobile wireless network accessibility vs. resilience is disturbingly trending in opposite directions. The demand for cellular networks with greater capacity and bandwidth appears to be the primary factor in expanding coverage nationwide, while resilience often becomes a secondary thought. Gerry Smith illustrates to what lengths carriers will go to avoid equipping BSs with appropriate backup capacity, "Mobile telephone companies have for years lobbied to kill rules that would have forced them to maintain backup power at their cell phone towers."[16]

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[13] "Strong Demand for Smartphones and Heated Vendor Competition Characterize the Worldwide Mobile Phone Market at the End of 2012," press release, IDC, http://www.idc.com/getdoc.jsp?containerId=prUS23916413#.UQ2_S47R3dk.

[14] T. G. Lewis, *Bak's Sand Pile: Strategies for a Catastrophic World* (Williams, CA: AGILE Press, 2011).

[15] Judith Rodin and Felix Rohatyn, Lazard, Co-Chairs, *NYS 2100 Commission Recommendations to Improve the Strength and Resilience of the Empire State's Infrastructure*.

[16] Gerry Smith, "Wireless Industry Resisted Calls to Back Up Cell Towers before Sandy," *Huffington Post*, sec. Tech, Nov 4, 2012.

It is expected that resilient systems will be able to withstand shocks and stresses from critical incidents and still be able to function as intentionally designed.[17] However, the fragility of cellular networks affected by recent disasters within the last ten years, have demonstrated otherwise. For instance, Superstorm Sandy affected wireless phone access by knocking 25 percent of the Northeast's cell towers off-line, with the primary cause associated to power failure.[18] Such singular dependency on power conversely supports resilience.

Exacerbating this issue are states considering legislation supporting the major telecoms strategic direction of decommissioning legacy landline phone service, replacing them with an all-digital wireless network comprised of cellular base stations—presumed to offer greater capacity and functionality, but inherently not as resilient during power outages compared to their landline counterpart.[19] AT&T is planning to have all its landline phone service turned off by 2020, with Verizon pursuing similar policies.[20] This fundamental change in policy is affecting "universal service," an agreement constructed between the telephone industry and the government ensuring every family in the U.S. phone service.[21] Florida, North Carolina, Texas, and Wisconsin have already repealed universal landline requirements.[22] Several other states such as Ohio, Indiana, Alabama, Georgia, Mississippi and California are pursuing the same course of action to eliminate the requirement for service providers, such as Verizon and AT&T to maintain these legacy copper landlines.[23] The changes will affect everyone across the country; however,

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[17] Judith Rodin Felix Rohatyn, Lazard, Co-Chairs, *NYS 2100 Commission Recommendations to Improve the Strength and Resilience of the Empire State's Infrastructure*.

[18] Sinead Carew, "Hurricane Sandy Disrupts Northeast U.S. Telecom Networks," Reuters, http://mobile.reuters.com/article/idUSBRE89T0YU20121030?irpc=932.

[19] Cecilia Kang, "Landline Rules Frustrate Telecoms," *The Washington Post*, April 13, 2012.

[20] Associated Press, "Copper Telephone Lines Fade Away, Worrying Regulators and Consumers." *The Oregonian*, July 8, 2013. http://www.oregonlive.com/business/index.ssf/2013/07/copper_telephones_lines_fade_a.html.

[21] National Telecommunications & Information Administration, "Universal Service," http://www.ntia.doc.gov/legacy/opadhome/opad_us.html.

[22] Kang, *Landline Rules Frustrate Telecoms*, 1.

[23] Kang, *Landline Rules Frustrate Telecoms*, 1.

the elderly and those living in distant rural areas that have poor coverage may be at greater risk.[24]

The relevance of this issue was evident in such catastrophes as Hurricane Katrina (2005), the Derecho (2012) and Superstorm Sandy (2012). Many were unable to communicate with others or more importantly, summon help, as a result of cell tower base stations going off-line, while those with conventional landlines had some form of functionality.[25] Carriers are not proactively equipping base stations with adequate backup power or utilizing alternative/renewable energy technology such as photovoltaic or wind power to allow them to operate independently of the power grid.[26]

First responders throughout the country have long endured the difficulty of handling complex large-scale incidents requiring the response and collaboration of various agencies, and jurisdictions. During the late 1990s, the Public Safety Wireless Advisory Committee reviewed such grievances and outlined recommendations to facilitate better communications capacity among disparate responding emergency workers. [27] The report outlined the critical requirements needed to establish an Interoperable Public Safety Network, ultimately capable of providing communications synergy. This would later serve as the foundation for the NPSBN, which recently received legislative approval over a decade later under the *Middle Class Tax Relief and Job Creation Act of 2012*.[28]

The NPSBN is proposed to operate over or leverage some capacity of commercial base stations equipped with next generation cellular technology known as 4G-LTE[29]

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[24] "Copper Telephone Lines Fade Away, Worrying Regulators and Consumers."

[25] Anton Troianovski, "Corporate News: Outages Highlight Worries on Phone Networks," *Wall Street Journal*: Nov 5, 2012.

[26] Tweed, *Why Cellular Towers in Developing Nations are Making the Move to Solar Power*.

[27] *Final Report of the Public Safety Wireless Advisory Committee to the Federal Communications Commission and The National Telecommunications & Information Administration*, September 11, 1996.

[28] *Middle Class Tax Relief and Job Creation Act of 2012*, Public Law 11299-6, (February 22, 2012): 126 Stat., 156.

[29] "Long Term Evolution (LTE) Public Safety Information Sheet," FCC, http://transition.fcc.gov/pshs/docs/LTE_Info_Sheet_09082010.pdf.

either as primary or redundant failover.[30] The FCC Long Term Evolution (LTE) Public Safety Information Sheet explains how this next generation cellular technology works. "4G is based upon an all Internet Protocol (IP) packet switched network that supports mobile broadband access, as well as multi-media applications with high data rates and low latencies utilizing spectrum efficiency by smooth handoffs and seamless roaming across multiple networks."[31] This raises concern, as the commercial wireless network has not been mandated to equip their BSs with backup power. Understanding this critical deficiency and reliance of leveraging commercial wireless infrastructure, the NPSBN runs the risk of failing to provide mission critical operability for first responders when the loss of grid power occurs.

In order to remedy some of these deficiencies with BSs in the U.S., an analysis of a comparable cellular network, which encounters frequent power outages, may provide insight for resiliency. India's enormous mobile phone market, the second largest globally, is supported by approximately 400,000 BSs spread throughout the country.[32] Keeping these cell towers functioning is a daunting task for telecoms with the government playing a central role. Many areas in India are supported by an under developed/inadequate power grid, which goes off line frequently. Cities are left in the dark at times up to fourteen hours.[33] When power is lost, BSs require some form of back-up power in order to continue functioning. As such, telecoms have relied substantially on diesel generators to provide this continuity of service. Government involvement stems from subsidizing diesel throughout the country, which has become an economic burden as India lacks adequate domestic oil production, reliant on foreign imports.[34]

In order to transition away from a diesel dependent cellular network, the government drafted environmentally sustainable standards outlined in the NTP-2012. The NTP posits the framework for India to achieve a dominant technological and economic

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30 *Middle Class Tax Relief and Job Creation Act of 2012,* 126 stat. 15611-26 Stat., 256.

31 "Long Term Evolution (LTE) Public Safety Information Sheet."

32 Tweed, *Why Cellular Towers in Developing Nations are Making the Move to Solar Power*.

33 Naikodi, "Solar-Wind Hybrid Power for Rural Indian Cell Sites," 2010.

34 "The World Factbook," https://www.cia.gov/library/publications/the-world-factbook/geos/in.html.

role globally through the expansion of its mobile cellular network. The policy strategizes achieving these goals by tapping into the majority of the population residing in these rural areas with cellular technology. As such, significant changes are sought to mitigate the effects of power outages. In order to provide uninterrupted services during power outages, the NTP proposed using renewable/alternative energy. Telecoms in India have proactively begun this transformation with Mumbai rebranded as a "Green City."[35] The changes reflected in the NTP offer obvious potential for countries that have inadequate power grids. However, there is potential application in developed nations, where renewable/alternative energy can provide much-needed resilience to fragile cellular networks that lack appropriate back-up power for continuous service. There is also the added benefit of lowering carbon emissions by eliminating the predominant mechanism for back-up power, diesel generators.

The purpose of this research is to direct attention to the importance of cellular base station (BS) functionality during power outages and illustrate how these assets require modification to provide critical communications for the public to summon aid, and first responders to coordinate response and recovery efforts. Prior research offers strategies to implement post-disaster remediation supplanting failed localized communication infrastructure. This mitigating strategy requires substantial time, labor, and planning to deploy, which subsequently detract from conducting immediate response and recovery during the onset of the emergency.[36] This research is intended to highlight and propose a path forward for resiliency in mobile cellular communications infrastructure using renewable/alternative energy—minimizing the need to implement these timely stopgap measures.

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[35] "Indus Towers' Sites Turn Green in Mumbai," LightReading India, News Wire Feed, http://www.lightreading.in/lightreadingindia/news-wire-feed/154821/indus-towers-sites-green-mumbai.

[36] See WWW.FEMA.Gov, "Mobile Emergency Response Support-Support Considerations."

C. RESEARCH QUESTIONS

1. Are there common reasons for cellular base stations failure?

2. Can the strategic direction taken by the Indian government to increase resilience within the country's mobile cellular network utilizing renewable energy be considered a viable policy option for the United States to pursue?

   - Would implementing such a policy allow base stations to provide continuous service during power failures?
   - Can the use of alternative and renewable energy provide base stations with the capacity to be self-sustainable, no longer reliant on grid power?
   - How could proposed changes to base stations affect the construction of the NPSBN?

D. METHOD

The increasing role of smart phones and mobile devices supported by cellular technology cannot be ignored, as it is leveraged in every aspect of our daily lives—to the extent that many no longer require a home phone. This trend has caused the telecom industry to revaluate maintaining the legacy infrastructure supporting home phones for service provided over the airwaves through BSs. As the benefits offered are tremendous, such as ubiquitous coverage; the inherent fragility experienced during power outages is marginalized. The U.S. government will need to evaluate if this trade off is an acceptable risk. An account of disasters occurring during the past ten years has shown how unstable U.S. communications infrastructure has become. More importantly the strategic direction proposed by telecoms to migrate to a predominantly wireless business model limiting overall network diversity might create a risk too great to allow.

This research method included four steps:

1. The initial objective of this research was to determine if there were common reasons for BS failure. Three storms were analyzed: 1) Hurricane Katrina, 2) Derecho, and 3) Superstorm Sandy. These particular storms were sampled because they

occurred in the United States within the past 10 years and due to the significant impact they had on telecommunications systems. Each inflicted damage to various segments of critical infrastructure, affecting the ability for the public and first responders to communicate and coordinate rescue and recovery. The researcher reviewed contributing factors that lead to various telecom failures caused by these storms in an effort to detect commonalities, if any. The identification of these common causes for service disruption was used to develop mitigating strategies.

The major components of the telecom network were assessed, specifically focusing on their interdependency. Base stations were examined to determine how they functioned once grid power was lost. The researcher explored how telecom service providers planned to provide coverage during power outages. This entailed an assessment of the back-up power supply installed at BSs. BS locations were also factored in to determine the impact of tidal surge, or physical damage from high winds. The data utilized for the analysis came from the FCC government publications, such as after action reports, lessons learned assessments, Congressional research, peer reviewed journal articles, and press releases. Using storms provides obvious limitations as other kinds of natural disasters may affect BSs differently. However, examining storms was useful, because they are the most common.

2. The researcher then examined the strategic direction taken by the Indian government to increase resilience within the country's mobile cellular network utilizing renewable energy. India was used as a comparative model because of its enormous cellular network consisting of 400,000 BSs, which is greater in size than the U.S. (at 300,000). The country was also selected to analyze how they provide continuous cellular service with an inadequate power grid that fails frequently. Their practices offer a model for U.S. telecoms to handle power outages. The policy decisions and time frame outlined in their strategic plans reflects how a nation with a larger cellular network is capable of migrating to renewable/alternative energy, and the practicality of achieving such a goal. In addition, the researcher sought to answer if implementing such a policy in the United States would allow base stations to provide continuous service during power failure. The Indian government's strategy to improve telecommunications resilience is reflected in

NTP-2012. The NTP-2012 posits the technological and conceptual framework for India to achieve economic superiority globally through a robust commercial mobile cellular network. It also envisions reducing the country's costly dependence on imported diesel, while lowering harmful carbon emissions. This perspective plays a significant part in what U.S. telecoms should envision achieving.

An analysis of the NTP-2012 was conducted to evaluate the strategic application for the commercial mobile cellular infrastructure of the United States. Ultimately the changes considered for the U.S. would be implemented to harden base station operational capacity. Hardening provides supplemental protection to include redundant connectivity, backup power, and structural integrity for BSs.[37] To determine the practicality of this policy for U.S. deployment, the researcher focused on the core concepts that draw direct parallel to U.S. governance of telecommunications practices. The primary objective was to consider what changes should be implemented and to identify the agency best suited to carry it out. The data used for this analysis relied on the NTP-2012, journal articles, press releases, the Middle Class Tax Relief Act of 2012, academic studies and industry reports.

3. The researcher further considered whether the use of alternative and renewable energy would provide base stations with the capacity to be self-sustainable, no longer reliant on grid power. Renewable/alternative energy were explored, which would support the global goals of lowering harmful carbon emissions produced by diesel generators, the predominant back-up power supply for BSs, along with the increased role in supporting remote telecom installations. For example, providing power to BSs in areas not supported by commercial grid power. In order to do so, an exploration of the limitations in conventional modes of powering BSs and how they react during power outages was undertaken. Subsequently, alternative, and renewable energy were examined to determine if they could provide ample back-up power during power failure, with the potential for self-sustainable capacity independent of grid power.

The researcher reviewed both traditional modes of providing power to BSs (to include AC grid power, diesel generators, and battery), and alternative and renewable

[37] Moore, *The First Responder's Network and Next-Generation Communications for Public Safety: Issues for Congress*.

forms of energy to include fuel cells, photovoltaic (solar), and wind. The data included industry reports, academic research, journal articles, government publications to include congressional research, Department of Energy, and after action reports.

4. Finally, the researcher assessed how proposed changes to base stations could affect the construction of the NPSBN. The NPSBN was factored into this research because of its potential dependency on the commercial cellular network. The fragility of the U.S. commercial cellular network has direct implications for NPSBN to provide mission critical capacity to first responders. An exploration of the NPSBN was undertaken as this public safety network is proposed to provide interoperable communications across the country to first responders from various agencies and jurisdiction over cellular technology and infrastructure. The agreed upon standard it will operate over, 4G-LTE, is nascent within the commercial wireless industry. There has not been an official directive issued by FirstNet, the sanctioned authority overseeing its construction to have the NPSBN operate over the commercial cellular network or construct and entirely new public safety network.

The implications of this research highlight current technological and construction deficiencies within the U.S. commercial cellular network. The purpose of this analysis is to provide FirstNet with an opportunity to evaluate policy and cost implications to either construct an entirely new public safety cellular network or work with the FCC and telecom service providers to propose changes to harden the commercial network in order to provide the expected operational capacity to support first responders. The researcher analyzed the Middle Class Tax Relief Act of 2012, which outlines how the NPSBN should operate in order to determine what is conceptualized for the NPSBN. The analysis was limited to the infrastructure proposed for the NPSBN and concentrated on how BSs would support its functionality during power outages. The data for the analysis came from the Middle Class Tax Relief Act of 2012, the 9/11 Commissions Recommendations, congressional hearings, government reports, the Federal Communications Commission, telecommunications companies, journal articles, and press releases.

There are inherent limitations associated with determining the actual cost of equipping a BS with renewable/alternative energy, which is dependent on the physical

location of the structure. For the NPBSN, there are multiple layers beyond BSs that have significant effects on the performance of the network that are beyond the scope of this research as well.

E. OVERVIEW OF UPCOMING CHAPTERS

The upcoming chapters comprise the following:

II. *The Literature Review*. The available literature addresses: 1) mobile cellular networks and the lack of resilience during natural disasters, 2) India's National Telecommunications Policy for 2012, 3) alternative and renewable forms of primary and back-up power for base stations, and 4) the National Public Safety Broadband Network.

III. *Contributing Factors Leading To Base Station Failure*. Since 2005, several natural disasters have caused major disruptions in telecommunications systems. Hurricane Katrina (2005), Derecho (2012), and Superstorm Sandy (2012) are examined for their specific impact on telecommunication networks and the difficulties experienced because of potential deficiencies. Within this section, the researcher reviewed the contributing factors that lead to the various failures caused by these storms in an effort to identify commonalities, if any.

IV. *Communications Limitations for First Responders At Emergency Incidents*. Within this section, a glance at major historic events relating to public safety communications failures for first responders are considered, and how they lead to the creation of the National Public Safety Broadband Network. There is a chronological explanation of the legislation, congressional hearings, and ultimately the passage of the Middle Class Tax Relief and Job Creation Act of 2012 that codifies the requirements and parameters to build the NPSBN.

V. *India's Economic Growth and the Role of Renewable/Alternative Energy in Its Mobile Cellular Network*. Within this section, an exploration of India's economy is undertaken analyzing specific policy changes responsible for foreign investment, lowered foreign oil dependence, and the role of mobile cellular communication. There is also an

examination of alternative/renewable energy's potential role supporting BSs power requirements for back up and primary use.

VI. *India's Mobile Telecommunications Strategy, A Model for U.S. Application.* India's NTP strategy is a culmination of the nation's commitment to achieving economic superiority through technological advancements in mobile cellular infrastructure. There is also a parallel effort to provide socio-economic parity to its under serviced majority population with equal emphasis on environmental consciousness. There are four main strategies targeted within the NTP that have direct implications for U.S. application: 1) Expanding its commercial mobile wireless network to rural underdeveloped regions with inadequate grid power, 2) Creating a robust resilient mobile wireless network capable of withstanding disasters both natural and manmade, 3) Incentives for corporate adoption and 4) Investing in renewable/alternative energy to power base stations in order to lower fossil fuel dependency and harmful carbon emissions.

VII. *Recommendations and Conclusions.*

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II. LITERATURE REVIEW

The available literature addresses: 1) Mobile cellular networks and the lack of resilience during natural disasters, 2) India's National Telecommunications Policy for 2012, 3) Alternative and renewable forms of primary and back-up power for base stations, and 4) The National Public Safety Broadband Network. The core body of literature is produced by: the FCC, Department of Energy, and other government publications to include the Indian government, peer-reviewed journal articles, press releases, research and development from energy and telecommunications companies, scientific periodicals, academic think tanks, and wireless mobile carrier publications.

A. THE IMPACT OF NATURAL DISASTERS ON TELECOMMUNICATIONS

There is extensive literature analyzing the impact of natural disasters on critical infrastructure. However, a minority provides context on the telecommunications perspective. Within this compilation of literature, a consensus purports that the commercial mobile cellular networks are fragile—exhibiting an acute dependency on grid power. The October 2012 issue of *New York Times Business Day-Technology* reported on the impact of Superstorm Sandy, illustrating how BSs have a critical dependency on grid power: "Power system failures throughout the Northeast have been the main culprits in the shutdown of more than 20 percent of the cell towers in 10 states."[38] The collection of literature within this subsection is produced from press releases, peer-reviewed journal articles, telecommunications research and development labs, and government after action reports.

The *Federal Response to Hurricane Katrina, Lessons Learned 2006* offers context for how Hurricane Katrina affected overall critical infrastructure cascading to telecommunication failure through the experiences encountered by industry personnel and emergency managers:

[38] Edward Wyatt and Brian Chen, "FCC Details Storm-Related Cellphone Problems," *The New York Times*, sec. Business Day-Technology, October 31, 2012.

> D.H.S should review our current laws, policies and strategies relevant to communications…with support from the Office of Science and Technology Policy, should develop a national emergency communications strategy that supports communications operability and interoperability.[39]

The document offers an overall assessment with limited analysis on the mobile cellular network. The report ultimately postulate support for a National Interoperable Public Safety Network.

A more extensive and detailed assessment regarding the telecommunications impact caused by Katrina can be found in an article sponsored by the National Science Foundation (NSF), titled “Telecommunications Power Plant Damage Assessment Caused by Hurricane Katrina—Site Survey and Follow—Up Results” by Kwasinski, et al. The article analyzes how telecommunications were disrupted through key points of failure in power distribution—affecting both wired and wireless networks. It proposes mitigating strategies with the consensus view on BSs migrating away from grid power, to renewable energy (photovoltaic), and alternative fuels.[40] Kwasinski, et al. recommends, “the telecom industry should develop a common infrastructure design and construction guideline for coastal areas with high risk of hurricanes, as it is done in earthquake prone regions.”[41]

Supplementing the Katrina Telecommunications analysis is an article titled “Critical Infrastructure Analysis of Telecom for Natural Disasters,” produced by Bell Laboratories, Lucent Technologies, and Sandia National Laboratories.[42] The analysts utilized the Network Simulation Modeling and Analysis Research Tool (N-SMART), “developed to support detailed wireline and wireless network simulation,”[43] to run ad hoc simulations on the impact from natural disasters. The study conducted various

[39] United States, Executive Office of the President, Assistant to the President for Homeland Security and Counterterrorism, *The Federal Response to Hurricane Katrina: Lessons Learned*, White House, 2006.

[40] Ibid.

[41] A. Kwasinski et al., “Telecommunications Power Plant Damage Assessment for Hurricane Katrina– Site Survey and Follow-Up Results,” *Systems Journal, IEEE* 3, no. 3 (2009): 277–287.

[42] O’Reilly et al., “Critical Infrastructure Analysis of Telecom for Natural Disasters,” 2006.

[43] Roger M. Whitaker, Larry Raisanen, and Steve Hurley, “The Infrastructure Efficiency of Cellular Wireless Networks,” *Computer Networks* 48, no. 6 (August 19, 2005), 1.

telecommunications model testing with alternative strategies. The prevailing strategy relied on a readily accessible supply of fuel to keep generators operating; an issue Sandy proved problematic in the event of a fuel supply disruption.

The Federal Communication Commission's "Impact of the June 2012 Derecho on Communications Network and Services, Report and Recommendations, January 2013" provides a detailed overview of how the telecom infrastructure reacted to the Derecho. The report separates various components within the wired and wireless network and offers context in support of the consensus view. For instance, it notes that, "the two main reasons reported for cell site outage were loss of power and the disabling of transport facilities that carry calls from cell sites to mobile switching centers."[44] The report offers a relational overview of the events that transpired beginning with the loss of power to how the dependent components within the telecom network reacted. Subsequently, it expanded on the cascading failures that ensued once central offices (COs) went off-line from faulty diesel generators that failed to start. The report expands on current strategies employed by telecom service providers to provide back-up power to BSs, and COs commenting on their limitations; "cell towers began to lose all source of power (commercial, battery, generator) in the hours and days after the storm had dissipated."[45] The use of batteries and diesel generators by telecom industry is replicated across the swath of literature. The literature also draws attention to service providers failing to track and identify what form of back-up power is installed and to which specific BSs.

An overview of the impact of Superstorm Sandy is outlined in the "NYS 2100 Commission Recommendations to Improve the Strength and Resilience of the Empire State's Infrastructure, January 2013." An important factor is how the report defines "resilience [as] the ability of a system to withstand shocks and stresses while still maintaining its essential functions."[46] The document provides an overall assessment of New York State's critical infrastructure and looks at deficiencies in multiple sectors. It

44 Federal Communication Commission, *Impact of the June 2012 Derecho on Communications Network and Services. Report and Recommendations*, 2013, 36.

45 Ibid.

46 Judith Rodin and Felix Rohatyn, Lazard, Co-Chairs, *NYS 2100 Commission Recommendations to Improve the Strength and Resilience of the Empire State's Infrastructure*.

does not offer any specific recommendations in telecommunications. However, it does propose expanding NYS's commitment to pursue renewable energy, by offering incentives for the private sector to invest in alternative fuel sources. There are strategies proposed to offset the loss of grid power by creating micro-grids. "The 'grid' does not sufficiently allow, and certain regulatory requirements discourage, power sources and customers to be 'islanded' or run as a micro-grid to allow outages to be confined and enable more rapid recovery."[47] The report also postulates how investing in renewable energy will further enhance the states efforts in support of the Regional Greenhouse Gas initiative (RGGI) "an effort among nine Northeast and mid-Atlantic states to reduce CO emissions."[48]

The compilation of available literature offers insight from analyzing the events that transpired during and after these storms. They provide consensus on the limited operational capacity of the equipment installed by telecom providers to provide back-up power. For example, the use of batteries provided mere hours of additional service for BSs. The literature brings up a significant point—how service providers are not accounting for what forms of back-up power is actually installed to which BSs. The majority of the literature identified the practice of equipping diesel generators to BSs as unreliable due to the critical dependency on accessible fuel. Finally, the literature agrees on transitioning to renewable/alternative forms of energy to provide primary and back-up power to BSs.

B. INDIA'S ECONOMY AND MOBILE TELECOMMUNICATION NETWORK

The available literature on India's economic growth and Telecommunications strategy is compiled from the National Telecom Policy 2012, press releases, business and economic journals, the World Fact Book, and academic research.

The literature offers insight into what specific sectors propelled the country from dismal economic times to a competitor for world economic power. Dushyant Gosai

[47] Judith Rodin and Felix Rohatyn, Lazard, Co-Chairs, *NYS 2100 Commission Recommendations to Improve the Strength and Resilience of the Empire State's Infrastructure*.

[48] Ibid.

outlines relevant changes made to stimulate India's economy in an article for the International Policy Digest.[49] "There were three major driving forces behind India's economic growth and prosperity after economic reforms of 1991; Increased foreign direct investment, India's expertise in information technology and increased domestic consumption because of a growing middle class population."[50] The article goes on to mention the projected decrease in GDP according to Morgan Stanley and HSBC, which forecast fiscal years 2013 and 2014 from 5.2 to 5 percent and from 6.2 to 6 percent. Even with the drop in GDP, India is still positioned to out perform the U.S. and European economies.[51]

As India continues to develop, it is poised to expand its economic potential and growth second only to China. A major sector recognized to support this effort is telecommunications. India's National Telecom Policy-2012 states, "Telecommunications has emerged as a key driver of economic and social development in an increasingly knowledge intense global scenario, in which India needs to play a leadership role."[52] The document outlines a national strategy to leverage technology as an equalizer in providing essential services such as health, education, and employment to its population. More importantly the document equates a robust mobile cellular network as the primary mechanism to expand the nation's capacity to generate revenue from mobile commerce. It also recognizes the economic stagnation within its rural areas is a factor of limited to nonexistent telecommunications services. This key segment represents the majority population at 68 percent, which the NTP identifies as the main demographic to fuel India's future growth.

The telecom market in India has experienced significant progress over the past decade propelled specifically by the mobile phone market. As of February 2012, there were 943 million telephone connections with the "cellular segment, which alone

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[49] Dushyant Gosai, "History of Economic Growth in India," http://www.internationalpolicydigest.org/2013/04/24/history-of-economic-growth-in-india/.

[50] Ibid.

[51] Ibid.

[52] *India's National Telecom Policy - 2012*.

accounted for 911 million connections."[53] The "NTP-2012…[envisions] leveraging telecom infrastructure to enable all citizens and businesses, both rural and urban areas, to participate in the Internet and web economy, thereby ensuring equitable and inclusive development across the nation." The document emphasizes the need for resilience within its telecom network by adequately preparing to mitigate natural and manmade disasters. The NTP further expands on how it will reach remote areas within the country that are not serviced by commercial grid power.

The document emphasizes the continued use and expansion of renewable energy to off set the country's reliance on diesel with aggressive milestones targeted over the next few years. The NTP-2012 provides India with a framework to achieve a national mobile telecommunication network capable of supporting private sector growth with parallel support for government security.

Finally, an article written by Jim O'Neill titled, "A 10-Step Program for India's Economy" lays out how to keep India on track to arrive at its economic potential. The document proposes specific sectors that need additional attention by the Indian government in order to continue growing its economy. For example, step ten states, "Protect the environment. India can't achieve 8.5 percent growth for the next 30 to 40 years unless it takes steps to safeguard environmental quality and use energy and other resources more efficiently. Encouraging the private sector to invest in sustainable technologies can boost growth in its own right."[54]

The compilation of literature within this section provides consensus that India's economy requires further investment in sustainable resources, if it is to continue growing to its full potential. The inadequate commercial power grid provides challenges for their growth. The core political direction with the NTP provides structure for a sustainable future through the use of a robust cellular network. In order to have that network functioning at required capacity, renewable/alternative energy will play a significant part.

[53] *India's National Telecom Policy - 2012*.

[54] Jim O'Neill, "A 10-Step Program for India's Economy," Bloomberg.com, http://www.bloomberg.com/news/201300-622-3/a-10-step-program-for-india-s-economy.html.

There is limited information available within the NTP that identify how they will remedy their faulty commercial power grid. This presents a significant problem for the country's future prosperity.

C. ALTERNATIVE AND RENEWABLE ENERGY FOR BASE STATIONS

The literature surrounding renewable and alternate energy for cellular BSs is compiled from various scientific periodicals, research and development of energy companies, peer-reviewed journal articles, the U.S. Department of Energy, nongovernment organizations, and government publications. The overall consensus shows an increase in research and development to meet projected usage in order to lessen the demand for fossil fuels. Further, the primary mitigating strategy in the majority of literature calls for using renewable/alternative energy within mobile cellular infrastructure to provide resilience along with lowering carbon emissions created by diesel powered backup power generators.

The available literature looks at the ever-increasing role renewable/alternative energy is playing in the telecom industry for both primary and back-up power. The U.S. Department of Energy has supported the expansion of mobile cellular networks utilizing alternative energy for some years now as seen in an article titled "The Greening of XOHM" October 2008. Sprint, along with U.S. Department of Energy and the Environmental Protection Agency, embarked on a campaign to bring attention to local communities regarding the safety of fuel cells.[55] The article goes on to discuss how Sprint proposed expanding its cellular network to incorporate fuel cell alternatives as a back-up power source for its BSs.

Alternative energy fuel cells have continued to increase their role in cellular networks providing reliable back-up power, as noted in an article produced by U.S. Department of Energy titled "Calling All Fuel Cells," December 2012. The article highlights how cell towers equipped with fuel cells for back-up power provided continuous service to areas impacted by Superstorm Sandy. There is a comparison of how fuel cells performed against their diesel generator counterparts. Cell towers equipped

[55] Kevin Fitchard, "The Greening of XOHM," *Telephony* 249, no. 14, (Oct 2008), 39.

with fuel cells operated without issue, while those equipped with batteries or diesel powered generators were affected by the storm.[56] The article does not specify the exact locations these devices were deployed to, nor does it offer context on how service providers would be expanding their usage.

Literature depicts India at the forefront of the global transition away from fossil fuel dependent mobile cellular base stations to eco-friendly technology and design where alternative and renewable energy is at the core of its strategy. Katherine Tweed states in an article written for Scientific America titled *Why Cellular Towers in Developing Nations are Making the Move to Solar Power*, "India, which has about 400,000 base stations, the government has mandated that 50 percent of rural sites be powered by renewables by 2015."[57] The article further expands on the increased cost of fossil fuel and how utilizing alternative and renewable energy will eventually be significantly cheaper. There is additional literature produced from scientific journals providing a comparison of diesel generators, which is the primary source of back-up power for BSs and the savings offered by renewables.[58] The literature also identifies how using new technology can lower overall power consumption of BSs, which is a significant component in making renewables/alternative energy a viable alternative.

Additional literature illustrates how entire cities have already begun adopting renewable energy to support cellular communications. For instance, Indus Towers,' an Indian telecom service provider have strategically employed renewables to Mumbai, calling it a "Green City."[59] There are examples offered by renewable energy companies that have already deployed alternative and renewable energy to various islands that were directly impacted by hurricanes and were able to continue to function days after grid power was lost. Such examples support and offer context for potential U.S. application.

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56 Sunita Satyapal, "Calling all Fuel Cells," Department of Energy, http://energy.gov/articles/calling-all-fuel-cells.

57 Tweed, *Why Cellular Towers in Developing Nations are Making the Move to Solar Power*.

58 Naikodi, *Solar-Wind Hybrid Power for Rural Indian Cell Sites*, 69–72.

59 "Indus Towers' Sites Turn Green in Mumbai."

The compilation of literature within this section offers practical application on how to apply renewable and alternative energy to mobile cellular networks for both primary and back-up power. BSs operating on renewable/alternative energy during major storms provide empirical data to employ onto the U.S. commercial cellular network. For example, after Superstorm Sandy struck the Caribbean and the East Coast, at least 100 cell towers equipped with fuel cells in the Bahamas and the Northeast United States continued to operate without commercial grid power.[60] Acquiring the location and length of time these BSs functioned independent of grid power provides a good use case. Ultimately, the use of renewables/alternative energy supports the global consensus of lowering carbon emissions while increasing the performance of the cellular network. Such efforts are integral to lower our dependence on fossil fuel reflective within New York State's *2100 Commission Recommendations,* which notes: "to build on the success of the Regional Greenhouse Gas Initiative (RGGI), the state should encourage alternative fuel sources."[61]

D. THE NATIONAL PUBLIC SAFETY BROADBAND NETWORK

Many recommendations came from the *9/11 Commission Report* that created sweeping reforms in government. The report raises a major national issue of how emergency incidents are managed and the lack of interoperable communications among various agencies and jurisdictions, which supported the creation of a National Public Safety Broadband Network (NPSBN).[62] "The inability to communicate was a critical element at the World Trade Center, Pentagon, and Somerset County, Pennsylvania, crash sites, where multiple jurisdictions responded."[63]

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60 "When the Grid Fails: Fuel Cells Power Critical Infrastructure in Disasters." Fuel Cells 2000 and the Breakthrough Technologies Institute, http://www.fuelcells.org/base.cgim?template=reports_and_case_studies.

61 Judith Rodin and Felix Rohatyn, Lazard, Co-Chairs, *NYS 2100 Commission Recommendations to Improve the Strength and Resilience of the Empire State's Infrastructure,* 15.

62 Federal Communication Commission, "700 MHz Spectrum," FCC, http://www.fcc.gov/encyclopedia/700-mhz-spectrum.

63 National Commission on Terrorist Attacks Upon the United States. *The 9/11 Commission Report: Final Report of the National Commission on Terrorist Attacks upon the United States.* (New York: Norton, 2004), 397.

The majority of literature available related to the Public Safety Network is compiled from Congressional hearings, government reports, and technical background provided by the FCC. The *F.C.C Encyclopedia*[64] offers a historical overview, with significant context on legislation and activities supporting the efforts to create a National Public Safety Network.

The Middle Class Tax Relief and Job Creation Act of 2012[65] provide the necessary framework for developing the NPSBN. It lays out the core specifications to be followed, such as, initial funding, radio spectrum allocation, network architecture, platform standardization, while creating the First Responder Network Authority (FirstNet)—ultimately responsible to oversee the NPSBN's construction.

There is consensus in the need to have an interoperable communications network for first responders. The arrival and acceptance across mobile telecom service providers to migrate to 4G-LTE provides a substantial coverage area for the NPSBN to leverage.[66] However, there is debate on the network model to be used, which is proposed to leverage commercial or government constructed cellular base stations or a hybrid of both. Some public safety advocates voice the need to create a separate public safety network that does not cross over to the commercial infrastructure. This strategy is time intensive and cost prohibitive. Others view the use of commercial cellular infrastructure as a reasonable way to quickly stand up the NPSBN within a reasonable and cost effective time frame. Finally, there are those who feel there is practicality in having both networks; however, the public safety component should provide supplemental coverage in areas where the commercial network is lacking. Whichever method is chosen, the ultimate criticality is the need for BSs to be hardened against commercial power grid failure.[67]

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64 Federal Communication Commission, *700 MHz Spectrum.*

65 *Middle Class Tax Relief and Job Creation Act of 2012*, 126 stat. 15611-26 Stat., 256.

66 L. K. Moore, *Public Safety Communications and Spectrum Resources: Policy Issues for Congress* DIANE Publishing, 2010.

67 Ibid.

E. GAPS IN LITERATURE

There is a dearth of information regarding the length of time base stations can or have functioned during power outages. Further, there is no form of record keeping identifying the type of equipment installed to provide back-up power for BSs. This fact is brought to light in The *Impact of the June 2012 Derecho,* which notes: “It appears that most of the major providers do not retain records of or analyze the actual lifespan of their cell site batteries when they support the site during a loss of commercial or generator power.”[68] Additionally, BSs equipped with alternative energy back-up power sources that continued to function after the loss of grid power during Superstorm Sandy were not mapped. This information is vital, permitting telecom service providers and government agencies to realistically forecast which areas would be without cell phone access and how long the battery capacity would operate. Having such information in advance potentially presents efficiencies in resource deployment to standup portable cell cites or cellular on wheels (COWs) in areas that have no battery back-up capacity or limited alternative energy BSs. The researcher did not consider the emerging LightRadio technology currently under development by Alcatel-Lucent[69] that offers the potential to provide cellular service in a small device the size of ones hand. This technology may prove to disrupt the need for actual cell towers in the near future. However, there is limited literature available in regards to actual usage and deployment.

68 A Report of The Public Safety and Homeland Security Bureau, *Impact of the June 2012 Derecho on Communications Network and Services. Report and Recommendations,* 39.

69 Alan Burkitt-Gray, “Operators ‘Ready to Try’ Bell Labs’ Cubes in Small-Cell LTE, Says Alcatel-Lucent’s Marcus Weldon.”

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III. CONTRIBUTING FACTORS LEADING TO BASE STATION FAILURE

Since 2005, several natural disasters have caused major disruptions in telecommunications' systems. Hurricane Katrina (2005), Derecho (2012), and Superstorm Sandy (2012) are examined for their specific impact on telecommunication networks and the difficulties experienced because of potential deficiencies. Within this section, the contributing factors are reviewed that lead to the various failures caused by these storms in an effort to identify commonalities, if any. The major components of the telecom network were analyzed, with emphasis on their interdependency, as well as external logistic factors that play a key dependent role, such as the supply of fuel.

A. KATRINA

On August 29, 2005, Hurricane Katrina became the most destructive natural disaster in U.S. history, striking with 115–130 mph winds and intense storm surges, leaving the Gulf Coast region with 96 billion dollars in damages, over 1300 deaths, and 300,000 homes destroyed.[70] The storm impacted every aspect of telecom systems within the Gulf, damaging central offices (CO), cell tower base stations (BS), severing transmission links and disrupting the flow of petroleum—needed to keep portable generators running. It "caused complete communications failure which hampered rescue efforts…and made calls for aid impossible from the hardest hit areas."[71] The major phone carrier within the region, BellSouth, along with the major wireless carriers, experienced approximately 3 million lines out of service during peak hours of operation.[72] The majority of damage inflicted by Katrina can be attributed to storm surge followed by flooding.[73]

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[70] Executive Office of the President, United States. Assistant to the President for Homeland Security and Counterterrorism, *The Federal Response to Hurricane Katrina: Lessons Learned*.

[71] Kwasinski et al., *Telecommunications Power Plant Damage Assessment for Hurricane Katrina–Site Survey and Follow-Up Results*, 277–287, 1.

[72] O'Reilly et al., *Critical Infrastructure Analysis of Telecom for Natural Disasters*, 1–6.

[73] A. Kwasinski, "Effects of Notable Natural Disasters from 2005 to 2011 on Telecommunications Infrastructure: Lessons from on-Site Damage Assessments," 2011, 3.

In order to identify potential interdependencies, in the telecom network the researcher utilized the analysis produced in Telecommunications Power Plant Damage Assessment Caused by Hurricane Katrina—Site Survey and Follow-Up Results by Kwasinski et al. The analysis started with: 1) The power supply, 2) Central Offices, 3) Transmission links, and 4) Cell site base stations (BS). The report noted the centralized network components received far greater damage in comparison to the distributed side.[74] This resulted in cascading failures across the network to ancillary sites that drew connectivity and routing from Central Offices, such as BSs. The damage inflicted on COs was a function of their location within flood zones. Other mitigating circumstances related to construction practices. For example, certain COs were built on elevated foundations, or located on high floors, which were able to withstand the flooding.[75] Eighteen central offices became inoperable from a lack of fuel to power their onsite generators.[76]

There are approximately 3,000 base stations in the area affected by Katrina that sustained minimum damage. The predominant damage to BSs resulted from inconsistent construction practices. The majority of damaged BSs were located below the flood plane, while others outside of this area were affected minimally.[77] For the remaining BSs that remained intact, grid power dependency proved vital. Once the loss of power occurred, their battery banks lasted for mere hours. The lack of permanently installed back-up generators exacerbated the situation—those few sites equipped with generators quickly exhausted whatever fuel was initially on hand. The delivery of fuel became an issue due to the disruption of local fuel supply and obstructed roadways.[78]

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[74] Kwasinski et al., *Telecommunications Power Plant Damage Assessment for Hurricane Katrina–Site Survey and Follow-Up Results,* 1.

[75] Ibid.

[76] Kwasinski, *Effects of Notable Natural Disasters from 2005 to 2011 on Telecommunications Infrastructure: Lessons from on-Site Damage Assessments*, 1–9.

[77] Ibid., 2.

[78] Kwasinski et al., *Telecommunications Power Plant Damage Assessment for Hurricane Katrina–Site Survey and Follow-Up Results,* 4.

The overall damage to the telecom network in Katrina resulted in the failure of COs; caused by storm surge and faulty and fuel depleted diesel generators, which caused a chain reaction to downstream dependent BSs. In totaling, the lack of standardization where COs and BSs were constructed resulted in significant damage that could have been avoided. There were several recommendations made by Kwasinski et al. supporting the researcher's claim that BS reliability and continuity from the loss of grid power can be improved using renewable/alternative energy. "A better solution is to seek more independence from the electric grid by installing a permanent solar-assisted power plant to ease genset fuel demand after disasters and reduce operational cost yearlong."[79] After reviewing the critical failures in mobile cellular communications related to the loss of power, the FCC mandated that BSs be equipped with at least eight hours of back-up power.[80] Unfortunately, service providers successfully overturned this mandate in court. Finally, the Katrina lessons learned document recommended that D.H.S should work with the Office of Science and Technology Policy to develop a national emergency communications strategy that supports both operability and interoperability—referencing current laws, policies, and strategies relevant to communications.[81]

B. DERECHO

On June 29, 2012, the Derecho windstorm struck the mid-Atlantic region of the U.S. with minimal warning, knocking telecommunications and 9–1-1 operations off-line, inflicting twenty-two deaths, and leaving millions of customers without power—for some up to two weeks. The storm traveled six hundred miles in ten hours, with winds in excess of 60 mph impacting eleven states and the District of Columbia.[82] A Derecho, as defined by The National Weather Service is "a widespread, long-lived wind storm that is

79 Kwasinski et al., *Telecommunications Power Plant Damage Assessment for Hurricane Katrina–Site Survey and Follow-Up Results,* 4.

80 "When the Grid Fails: Fuel Cells Power Critical Infrastructure in Disasters."

81 Executive Office of the President, United States. Assistant to the President for Homeland Security and Counterterrorism, *The Federal Response to Hurricane Katrina: Lessons Learned*.

82 A Report of The Public Safety and Homeland Security Bureau, *Impact of the June 2012 Derecho on Communications Network and Services. Report and Recommendations*.

associated with a band of rapidly moving showers or thunderstorms.[83] In comparison to other storms, Derechos strikes with very little advance warning, similar to earthquakes, tornados, and man-made events for which there is minimal time for preparation.[84]

An interesting perspective with this particular storm is how it disrupted the telecom network not by physical damage or storm surge, but rather as an indirect consequence of the loss of grid power. Central offices (COs), which BSs connect to via fiber or microwave, were the first part of the telecom network affected by the Derecho. *The Impact of the June 2012 Derecho on Communications Networks and Services* notes: "Communications failure resulted, in significant part, from the loss of commercial power followed by generator failures."[85] COs were equipped with diesel generators to provide continuous service in the event of power failure. However, they were not as reliable as they were thought too be and crippled the downstream components that were reliant on a functioning COs, such as BSs. Nine out of 136 central offices experienced inoperable backup generators, leading to massive service interruptions throughout the region.[86] Derecho caused partial and complete service outages to 9–1-1, as a result of damage inflicted on the wireline telecom infrastructure, which extended for several days.[87]

The physical integrity of cell tower base stations withstood the impact of Derecho; however, this did not negate the loss of functionality once grid power was lost. Faulty generators and backup batteries that were equipped to certain BSs depleted rapidly.[88] Base stations were not designed or equipped with components capable of providing extended functionality during power outages. Batteries were the first layer of defense against the loss of power, providing operational capacity for a few hours. An unknown number of BSs were equipped with diesel generators, which were relied on to provide extended power beyond batteries. They too did not function as initially thought,

83 "ABOUT DERECHOS," NOAA, http://www.spc.noaa.gov/misc/AbtDerechos/derechofacts.htm.

84 A Report of The Public Safety and Homeland Security Bureau, *Impact of the June 2012 Derecho on Communications Network and Services. Report and Recommendations*, 1.

85 Ibid., 12.

86 Ibid.

87 Ibid.

88 Ibid.

and as such, failed to provide extended operational capacity to BSs. The inconsistency in equipping BSs with an appropriate back-up power source, created a cellular network that could not be relied upon during such a catastrophe, and as such perpetuated communications failure.

The initial cell site failures attributable to a combination of wire-line transport (back-haul), which resulted from COs going off-line due to faulty diesel generators not starting, and the inability of BSs to operate continuously without a functioning power grid. As BS did not receive substantial damage from the direct impact of the storm, their first level of failure manifested from the inability to route their communications to the wired network, which is brokered by COs. The wireline failure cascaded across the network, responsible for the greatest service losses experienced in northern Virginia once Verizon's Arlington and Fairfax central offices loss functionality due to failed backup power.[89]

Within the following days, failure transitioned from the physical wire-line transport to insufficient battery and generator capacity as repairs to the back-haul infrastructure started to return online.[90] As repairs brought COs to operational capacity, BSs were still without grid power and lacked the ability to operate without it. The report draws attention to the U.S. telecom network design and limitation during power outages highlighting the severity of backup power for cell sites. There is additional emphasis on service providers failing to track the amount of time batteries are actually powering cell sites during power outages. The lack of this information creates a void in forecasting service disruptions of the actual mobile wireless network. The Derecho revealed how interdependent telecom systems are and how sensitive they are dependent on power.

89 A Report of The Public Safety and Homeland Security Bureau, *Impact of the June 2012 Derecho on Communications Network and Services. Report and Recommendations*, 1.

90 Ibid.

C. SUPERSTORM SANDY

On October 29, 2012, Superstorm Sandy struck the East Coast of the U.S., leaving damage second only to Hurricane Katrina alone. The majority damage inflicted on the New York coastline stemmed from high winds and record-breaking high tides. The storm wrecked critical infrastructure, resulted in over 140 fatalities directly related to its impact, and caused damage in excess of $50 billion.[91] Widespread power outages were seen across Lower Manhattan resulting from flooded substations inundated by record setting storm surge.[92] Superstorm Sandy severely degraded the copper landline infrastructure, which supports conventional telecom services that have been around for over a 100 years. As services are slowly restored to these communities in the North East, they will no longer be provided via copper landline. Verizon has chosen to provide telephone services to residents by wireless only access, with increased cost and less overall service. Residents will not have ability to fax, connect alarm systems, or more important connect medical devices to their doctors office for monitoring.[93] This decision is in line with the telecom industries overall goal of abandoning landlines by 2020.[94]

The vast telecom failure throughout New York City resulted from a cascading effect triggered from the loss of grid power. This was attributed to substation failure due to flooding and manual shutdowns implemented by Con Edison, as a protective measure to limit the destruction of energized underground equipment.[95] Manhattan experienced a power outage that extended south of 39th street. At the onset of power failure, telecom systems operated on back-up power, if they were so equipped—consisting primarily of batteries or diesel generators. These stopgap measures provided minimum continuity of services.

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91 E. S. Blake, T. B. Kimberlain, R. Berg, J. P. Cangialosi, and J. L. Beven II, *Tropical Cyclone Report Hurricane Sandy,* National Hurricane Center, 2013.

92 Matt Smith, "Sandy Wreaks Havoc Across Northeast; at Least 11 Dead," CNN, http://www.cnn.com/2012/10/29/us/tropical-weather-sandy/index.html.

93 "Copper Telephone Lines Fade Away, Worrying Regulators and Consumers."

94 "Surprise! Your High-Tech Home Phone System could Go Dead in an Emergency."

95 Smith, *Sandy Wreaks Havoc Across Northeast; at Least 11 Dead*.

The second layer of telecom failure resulted from COs going off-line. Carew notes: “New York-based Verizon said the storm caused flooding at three Verizon central offices that hold telecom equipment in Lower Manhattan, as well as sites in Queens and Long Island.”[96] Physical damage and loss of power caused these critical nodes in the telecom network to cease to function. The effects rippled to down stream components that were fed by these sites, such as cellular base stations.

Cellular base stations were the final layer that failed to operate either from a lack of connectivity to COs or loss of primary grid power. The few that remained functional, running on either batteries or generators, if they were so equipped soon ceased operating once their diesel generators ran out of fuel. Sandy caused approximately twenty-five percent of cell towers in the region to fail.[97] The fuel shortage proved to be an unanticipated element in keeping BS generators running. The fragility of wireless cellular communications became very apparent once power was lost.

The uniqueness of Sandy can be seen in the impact it had on several sectors other than telecommunications that created an unforeseen void. The Buckeye pipeline is the primary source for petroleum in NYC and Long Island—running at maximum capacity to meet continued demand.[98] Once power was lost to this location, it created an acute shortage of fuel that took approximately two to three weeks to stabilize. The region was not prepared for such a shortage causing many critical facilities to cease operating. New York City Police Department’s Head Quarters and 9–1-1 operated on back-up diesel generators for five days. Airports within the region are fed directly from this pipeline and could not provide fuel for planes.

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96 Carew, *Hurricane Sandy Disrupts Northeast U.S. Telecom Networks*, 1.

97 Ibid.

98 Judith Rodin and Felix Rohatyn, Lazard, Co-Chairs, *NYS 2100 Commission Recommendations to Improve the Strength and Resilience of the Empire State’s Infrastructure*.

D. COMMON TELECOM FAILURES CAUSED BY STORMS

An analysis of Hurricane Katrina, Derecho, and Superstorm Sandy, exposes a systematic pattern of cell site failure triggered by several mutual factors associated with all three storms. The most common reason BSs cease to function were: 1) Commercial grid power failure, 2) Loss of wireline connectivity or back haul 3) Structural damage, and 4) Inadequate or lack of back-up power.[99] Very few BSs within areas directly impacted by these storms remained operational. The most prevalent failure seen across the swath of data was attributed to inadequate back-up power capacity.[100] An additional aspect of failure seen in Hurricane Katrina, and Superstorm Sandy was fuel starvation for those facilities or BSs equipped with diesel generators.

The loss of connectivity or back-haul generally occurs when the physical link (fiber optic cable or high-power microwave antennas) between BSs and central offices (CO) or any other intermediary mobile telephone switching office (MTSO) has been severed.[101] Another aspect that causes back-haul failure occurs when COs lose power, sustain physical damage or flooding.[102] This potentially creates a cascading effect, rippling throughout the network of adjoining BSs.[103] Consider BSs to be at the furthest point or edge in a network, while COs are at the center. Once a CO is knocked off line as a result of power loss or physical damage, the nodes at the edge or down stream no longer have the ability to process communications requests without a redundant connection to another unaffected CO.

An examination of BSs physically damaged by these storms illustrates a propensity for damage in certain likely locations. First, the area they were installed had a

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99 Executive Office of the President, United States, Assistant to the President for Homeland Security and Counterterrorism, *The Federal Response to Hurricane Katrina: Lessons Learned*.

100 A Report of The Public Safety and Homeland Security Bureau, *Impact of the June 2012 Derecho on Communications Network and Services. Report and Recommendations*.

101 Graham Booker et al., "Estimating Cellular Network Performance during Hurricanes," *Reliability Engineering & System Safety* 95, no. 4 (2010), 337–344.

102 O'Reilly et al., *Critical Infrastructure Analysis of Telecom for Natural Disasters*, 6.

103 Lewis, *Bak's Sand Pile: Strategies for a Catastrophic World*.

significant probability of damage, if it was constructed in a known flood zone.[104] Second, BSs built along coastal areas had a tendency to bear substantial flood damage.[105] The site survey provided by Kwasinski et al., of the areas impacted by Katrina offers insight how damage inflicted to BSs could have easily been averted, simply by constructing them outside of flood zones. Figure 1 is a map and diagram from *Telecommunications Power Plant Damage Assessment Caused by Hurricane Katrina—Site Survey and Follow-up Results* illustrating the severity of damage to BSs along the coastal and flood prone locations.

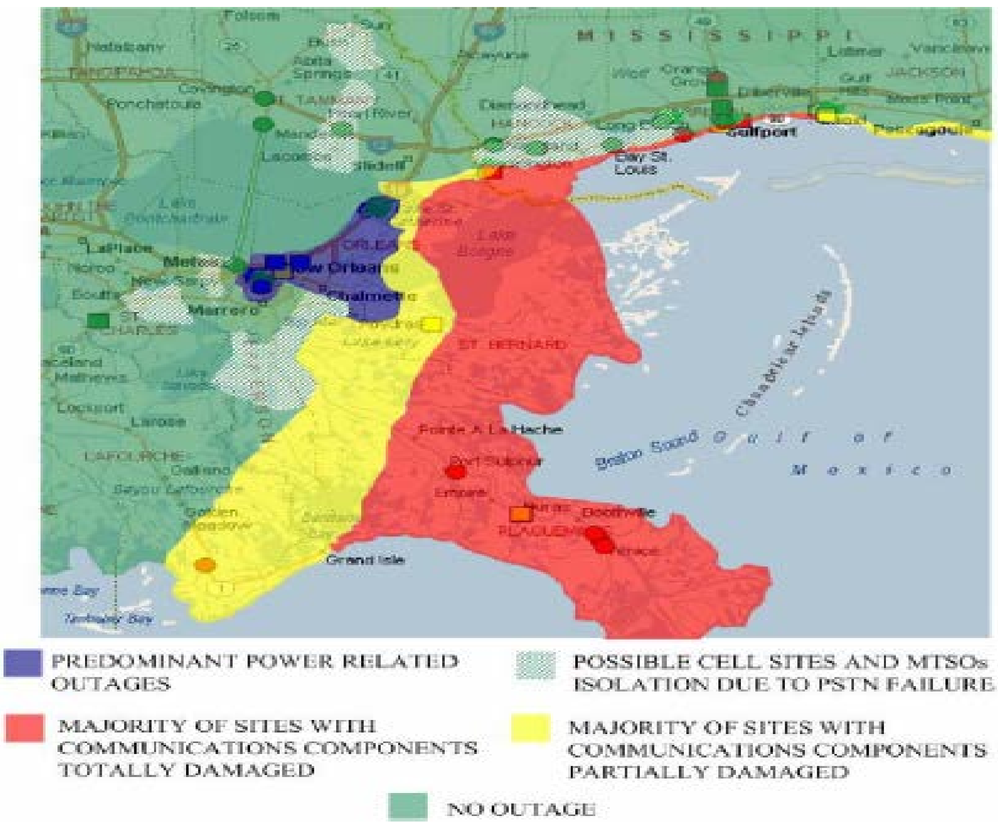

Figure 1. Map prepared by Kwasinksi et al. showing sampled cell site locations and predominant failure type zones.[106]

[104] Kwasinski et al., *Telecommunications Power Plant Damage Assessment for Hurricane Katrina–Site Survey and Follow-Up Results*, 277–287.

[105] Ibid.

[106] Kwasinski et al., Telecommunications Power Plant Damage Assessment for Hurricane Katrina–Site Survey and Follow-Up Results, 277–287.

Finally, natural disasters have a tendency to impact critical infrastructure, which often disturbs the fuel supply.[107] Superstorm Sandy and Hurricane Katrina impacted various aspects of critical infrastructure such as roadways, transmission and distribution power lines, bridges and tunnels. Superstorm Sandy caused widespread power failures throughout the Eastern seaboard.[108] The Buckeye pipeline ceased to operate as a result of the power grid going off-line. The pipeline serves as the main petroleum distribution hub for the North East. Once Buckeye stopped pumping, the impact rippled throughout the region resulting in an immediate shortage as the pipeline operates at capacity just to meet normal daily demands.[109] The shortage extended in excess of two weeks, resulting in New York and New Jersey implementing gas rationing. BSs and other facilities employing diesel generators eventually experienced fuel starvation due to Buckeye's failure.

Hurricane Katrina caused extensive damage to the power grid in several states. Some states, for instance Mississippi, had two-thirds of the electrical transmission and distribution system destroyed. The extent of the damage left residents without power for several weeks.[110] An illustration of how the impact of the fuel supply has a significant effect on telecommunications can be seen from the following example. Central offices rely heavily on diesel generators as their primary form of backup power. COs in Louisiana went off-line due to generator engine fuel starvation, related to local diesel supply and obstructed roadways—flooding was not a factor in these areas.[111]

Considering this hypersensitivity to grid power and the inherent operational failure that follows, why haven't wireless service providers proactively installed back-up power to BSs? There may be two potential factors. First, the U.S. has a relatively stable power grid, 99.97 percent reliable, compared to developing countries. And as such,

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[107] O'Reilly et al., *Critical Infrastructure Analysis of Telecom for Natural Disasters*, 1–6.

[108] Carew, *Hurricane Sandy Disrupts Northeast U.S. Telecom Networks*.

[109] Judith Rodin and Felix Rohatyn, Lazard, Co-Chairs, *NYS 2100 Commission Recommendations to Improve the Strength and Resilience of the Empire State's Infrastructure*.

[110] Kwasinski et al., *Telecommunications Power Plant Damage Assessment for Hurricane Katrina–Site Survey and Follow-Up Results*, 277–287.

[111] Ibid.

service providers calculate loss of functionality due to power failures as marginal considering the low probability of occurrence.[112] Second, there is a financial burden associated with retrofitting the 300,000 plus BSs nationwide. Although these considerations seem rational, they should not inhibit alternative cost-funded solutions to desist. In addition, the national upgrade to support the agreed upon next generation cellular standard 4G-LTE offers an opportune situation to incorporate appropriate back-up power to BSs.

112 "When the Grid Fails: Fuel Cells Power Critical Infrastructure in Disasters."

IV. COMMUNICATION LIMITATIONS FOR FIRST RESPONDERS AT EMERGENCY INCIDENTS

A. INTRODUCTION

Catastrophic events thrust the public and first responders into chaos and ambiguity while the crisis continues to unfold. The success or failure of an emergency response significantly hinges on how critically mobilized personnel are able to communicate and coordinate resources amongst each other. Within this section, a glance at major historic events relating to public safety communications failures for first responders are considered, and how they lead to the creation of the National Public Safety Broadband Network. The 9/11 Commission final report of the National Commission on Terrorist Attacks upon the United States (9/11 Commission) memorializes what can occur when such a circumstance is presented. The report emphasizes the difficulty experienced by first responders from various jurisdictions and agencies at the World Trade Center, Pentagon, and Somerset County in coordinating response and recovery efforts.[113] Twelve years later, on September 16, 2013, the Washington Navy Yard mass shooting that left 12 dead and four wounded reminds us we are no closer to resolving this issue as first responder's radio systems failed to provide adequate coverage and interoperability.[114] Emergency responders were ultimately forced to use cell phones to coordinate their tactical response.

The recommendations set forth by the 9/11 Commission supports the necessity of an Interoperable Public Safety Network—offering first responders from multiple jurisdictions and agencies the technological means to communicate with various emergency personnel at any given emergency incident nationwide. This however, proved to be an arduous endeavor, spanning in excess of ten years for final legislative approval. The passage of the Middle Class Tax Relief and Job Creation Act of 2012 (P.L. 112–96), adopted February 22, 2012, laid the framework for the development and financing of the

[113] National Commission on Terrorist Attacks upon the United States, *The 9/11 Commission Report: Final Report of the National Commission on Terrorist Attacks upon the United States,* 397.

[114] Kevin Bogardus, "Radios Failed during Navy Yard Attack, Emergency Responders Say," *THE HILL*, sec. HOME NEWS, Sep 19, 2013.

National Public Safety Broadband Network (NPSBN).[115] It is the first step towards a monumental change for public safety. The following chapter will cover the legislation, technical requirements, standards, and potential issues that lay ahead in constructing this NPSBN.

B. BACKGROUND

The communications failure experienced during 9/11 became a lightening rod for intense discussions, arguing the necessity for first responders to be able to communicate among each other. This however, was not the impetus for creating an interoperable public safety network. Coincidentally, September 11, 1996, The Public Safety Wireless Advisory Committee (PSWAC) published a report[116] outlining recommendations to assist first responders in communicating during major incidents/disasters requiring multi-agency response. The report states "the ability of officials from different Public Safety agencies to communicate with each other is limited…interoperability is key to success in day-to-day operations."[117]

The report further describes the unique wireless operational requirements, required for public safety. It states, the network should have: "1) dedicated capacity and/or priority access available at all times (and in sufficient amounts) to handle unexpected emergencies, 2) highly reliable (redundant) networks which are engineered and maintained to withstand natural disasters and other emergencies; 3) ubiquitous coverage within a given geographic area; 4) and unique terminal equipment (mobile or portable units) designed for quick response in emergency situations."[118] The public safety community understood the importance of creating national communications standards for first responders, however, until 9/11, and even after momentum would take years to build.

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115 *Middle Class Tax Relief and Job Creation Act of 2012,* 126 Stat., 15611-26 Stat., 256.

116 *Final Report of the Public Safety Wireless Advisory Committee to the Federal Communications Commission and The National Telecommunications & Information Administration.*

117 Ibid.

118 Ibid.

Since the recommendations of the 9/11 Commission, there have been a multitude Congressional hearings, testimony and legislation regarding the 1) implementation 2) radio spectrum allocation, and 3) technical requirements for the NPSBN. During this period, several significant disasters have since transpired, reinforcing the urgency in developing said network. The Federal Response to Hurricane Katrina: Lessons Learned notes that D.H.S should work with the Office of Science and Technology Policy to develop a national emergency communications strategy that supports both operability and interoperability—referencing current laws, policies, and strategies relevant to communications.[119]

C. DIGITAL TELEVISION TRANSITION AND PUBLIC SAFETY ACT 2005

On September 15, 1997, the NTIA commented on communications needs for the federal, state, and local public safety communities before the FCC. The NTIA raised concerns over the need for additional radio spectrum to address the continued growth of existing voice systems, emerging technology utilizing high-speed imaging systems, and greater communications interoperability supporting government agencies throughout public safety.[120] The short-term solution proposed reallocating approximately 25 megahertz of radio spectrum—reallocated from the television broadcast channels 60–69.[121]

The acquisition of this block of radio spectrum to public safety requires some elucidation. Channels 60–69 fall within the 700-megahertz (MHz) electromagnetic band of radio spectrum. There are 108 MHz of spectrum within this swathe, running from 698–806 MHz.[122] The 700 MHz Band offers significant propagation characteristics, primarily because of its location, which is immediately above the remaining TV broadcast channels. The most prevalent benefits are greater geographic coverage utilizing minimal

[119] United States. Executive Office of the President, United States, Assistant to the President for Homeland Security and Counterterrorism, *The Federal Response to Hurricane Katrina: Lessons Learned* 44.

[120] National Telecommunications & Information Administration, *NTIA Comments, Reallocation of Television Channels 6066-9, 76688-06 MHz Band B.*

[121] Ibid.

[122] Federal Communication Commission, *700 MHz Spectrum*.

infrastructure, along with the capacity to broadcast through buildings and walls.[123] The ability to leverage such robust coverage capacity while minimizing the need for additional infrastructure made this spectrum highly desirable for the public safety community—given their inherent mission. Figure 2 depicts the 700 MHz electromagnetic band of spectrum with the associated broadcast television channels.

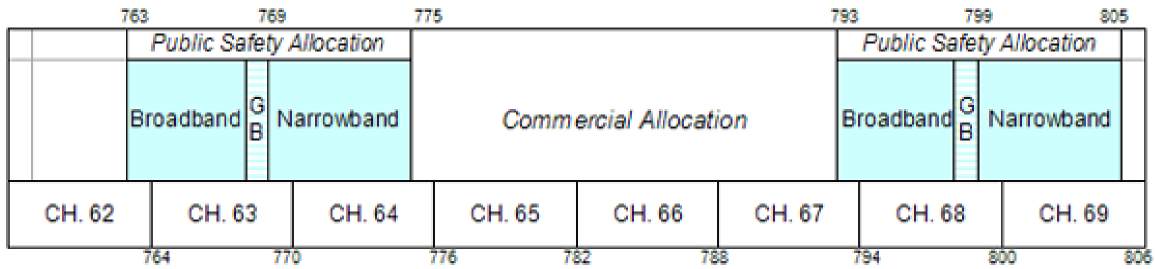

Figure 2. 700 MHz band plan for public safety services.

In order to reacquire this spectrum for public safety, legislation was drafted, compelling the broadcast television industry to transition away from this band of channels within a fixed time period.[124] The Digital Television Transition and Public Safety Act of 2005 provisioned "to terminate all licenses for full-power television stations in the analog television service, and to require the cessation of broadcasting by full-power stations in the analog television service, by February 18, 2009."[125] This was a milestone taken by Congress to ensure this valuable spectrum would be ready for public safety use.

D. NATIONAL PUBLIC SAFETY BROADBAND NETWORK

The Middle Class Tax Relief and Job Creation Act of 2012,[126] referred to as (The Act), represents the culmination of over a decade worth of testimony and debate directed at the necessity and feasibility of a National Public Safety Broadband Network. There are

123 Federal Communication Commission, *700 MHz Spectrum*.

124 *Deficit Reduction Act of 2005*, Public Law 10911-71, (FEB. 8, 2006): 120 Stat., 4.

125 Ibid., See (120 stat. 21).

126 Public Law No.11299-6 (enacted February 22, 2012).

several significant components codified within this legislation that formalize the framework for oversight, standardization, development, and implementation of the NPSBN.

First, the Act establishes an independent authority within the National Telecommunications & Information Administration (NTIA), known as the First Responder Network Authority (FirstNet). FirstNet, comprised of fifteen members, includes; the Secretary of Homeland Security, Attorney General of United States, Director of Office of Management and Budget, and twelve individuals appointed by the Secretary of Commerce. Together, they assume the crucial responsibility of establishing the NPSBN.[127] The board has exclusive authority allowing it to control funding, request for proposals and ensuring nationwide standards for interoperability. Committee members are required to have expertise in the following fields: 1) Public safety 2) Technical fluency in broadband communications, 3) Commercial telecom network building, and 4) Telecom financing and funding.[128]

The Act calls for FirstNet to ensure the NPSBN is safe, secure, and resilient, inclusive of protection from cyber attacks. Future equipment built to operate over the network must specifically be built with nonproprietary development standards, in order to create market competition. The Act recognizes developing this massive national network for the sole use of first responders is a daunting task that may not be practical to develop separately from the commercial wireless network of base stations, which already provide national coverage. The Act stipulates FirstNet to develop agreements with wireless providers in order to ensure the NPSBN has the capacity to “roam” onto commercial wireless base stations and gain priority access in times of emergency.[129] In addition, it reallocated vital spectrum from 758–763 MHz and 788–793 MHz, known as “D Block” to the NPSBN.[130]

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[127] *Middle Class Tax Relief and Job Creation Act of 2012*, 126 stat. 15611-26 Stat., 256.

[128] Ibid.

[129] Ibid., See SEC 6206 Roaming Agreements.

[130] Ibid., See SEC. 6101. Reallocation of D Block to Public Safety.

The NPSBN is an immense project that will require years to construct, operating over 4G-LTE, a standard cellular carriers have already begun migrating too. Considering the national coverage already provided by major mobile telecom providers, FirstNet should not discount leveraging some aspect of commercial BSs. In addition, as mobile telecom carriers are in the process of upgrading their cellular infrastructure to support 4G, it presents an opportunity to harden BSs with adequate back-up power, ensuring mission critical capacity to first responders during power outages. Finally, those reluctant to utilize the commercial cellular network for the NPSBN can reference the occurrences that transpired on September 16, 2013, where an active shooter killed 12 and wounded four at the Washington Navy Yard mass shooting. During the incident, first responder's encountered communications black out when their portable radios, which receive signal from radio towers dedicated solely for fire and police, failed to provide adequate coverage.[131] Cell phones were ultimately relied upon to coordinate response efforts, as they were the only devices able to receive adequate signal from commercial BSs. Thus, ensuring a negotiated agreement between commercial wireless carriers is essential for the NPSBN to become a reality within a reasonable time while keeping cost overrun at a minimum.

131 Bogardus, *Radios Failed During Navy Yard Attack, Emergency Responders Say*.

V. INDIA’S ECONOMIC GROWTH AND THE ROLE OF RENEWABLE/ALTERNATIVE ENERGY IN ITS MOBILE CELLULAR NETWORK

A. INTRODUCTION

Within this section, an exploration of India’s economy is undertaken analyzing specific policy changes responsible for foreign investment, lowered foreign oil dependence, and the role of mobile cellular communication. Changes to economic policy enacted in the early 1990s may have shifted the country from fiscal turmoil to a path of potential global economic dominance second only to China.[132] There is also an examination of alternative/renewable energy’s potential role supporting BSs power requirements for back up and primary use. Chapter VI then goes on to analyze the telecommunications policy outlined in India’s NTP-2012 to determine the potential applications for the U.S. commercial cellular network. The policy proposes how the country’s vast cellular network will significantly lower its consumption of diesel fuel through the use of renewable energy—supporting the global consensus to lower carbon emissions.

B. BACKGROUND

India, the world’s largest democracy with the second largest population at 1,220,800,359 estimated as of July 2013,[133] gained independence Aug 15, 1947 through nonviolent efforts, succeeding nearly 200 years of British colonial rule. The majority of the population, 68 percent, lives in predominantly rural areas lacking vital infrastructure such as power, utilities, and education. Its’ population offers a massive workforce both technical and labor rich. The nation has undergone significant economic and political transformation since 1991, fueling current and future economic prosperity. Mobile cellular communications play an integral part in this.

[132] O’Neill, *A 10-Step Program for India’s Economy*.

[133] “The WORLD FACTBOOK.”

In the early 1990s, India's economy faced growing inflation, unemployment, poverty and dramatic foreign exchange reserve.[134] India's economy was severely impacted by the Gulf War along with the fall of the Soviet Union. The Soviets' were a major trading partner and their predominant supplier of low-cost crude oil. As a result of the Soviet Union's collapse, India was forced to purchase oil in the open market.[135] This created an economic hardship, as the country relies heavily on imported crude. As of 2009, that figure was estimated at 2.768 million bbl/day with domestic production at 897,300 bbl/day.[136] A by product of the nation's crude oil dependence creates 1.696 billion metric tons of carbon dioxide as of 2011 estimations.[137]

In 1990, the country emerged from certain financial collapse as a result of policy changes from the Economic Reforms of 1991. The *Economic Reforms of 1991* enacted changes to macro economic policies "lowering tariff levels, exchange rate policy, liberalized licensing policy and also relaxed India's foreign direct investment (FDI) policy."[138] Over the past two decades, these changes have positively stimulated India's economy as seen in the increase of foreign investment. India's final economic stimulus can be attributed to the growing expertise and demand of information technology. The country has become the epicenter for many multinational companies' research and development due to the lower cost and the available local talent.[139]

India is projected to be the second largest economy globally by 2050, surpassing the U.S. as predicted by Jim O'Neill a former chairman of Goldman Sachs Asset Management who is a Bloomberg View columnist.[140] However, the road to prosperity is not paved in certainty. In order to arrive at its economic potential, India will need to make additional reforms across many sectors. Nevertheless, even with minimal growth, India is

134 Dushyant Gosai, *History of Economic Growth in India*.

135 Ibid.

136 "The WORLD FACTBOOK."

137 Ibid.

138 Dushyant Gosai, *History of Economic Growth in India*.

139 Ibid.

140 O'Neill, *A 10-Step Program for India's Economy*.

poised, as an economic driving force the world cannot ignore. O'Neill further highlights which specific sectors require further changes in *A 10-Step Program for India's Economy*;

1. Improve its governance through effective government
2. Primary and secondary education needs addressing, as many young people get little to no education
3. Improve colleges and universities. Developing institutions for excellence
4. Adopt an inflation target
5. Medium to long-term fiscal-policy framework, setting deficit of less than 3 percent of Gross Domestic Production (GDP) and debt of less than 60 percent
6. Increase trade with its neighbors. Exports to China predicted to be $1 trillion by 2050. However, exports to Bangladesh and Pakistan is minimal
7. Liberalize financial markets, increasing domestic and foreign capital
8. Innovate farming
9. Build more infrastructure
10. Protect the environment, through the use of energy and resource efficiency. Expand the private sector's investment in sustainable technologies

C. RENEWABLE ENERGY, HYBRID SOLAR-WIND BASE STATION

India has seen tremendous growth in cellular utilization becoming the second largest mobile phone market globally.[141] Supporting this massive cellular network are 400,000 base stations distributed throughout the country. The majority of these BSs receive power primarily from commercial electrical grid service. Grid power, however, is highly unreliable in certain rural locations resulting in regular power outages lasting at times in excess of fourteen hours per day, forcing service providers to equip BSs with diesel generators.[142] BSs servicing remote locations operate off diesel generators year

[141] Tweed, *Why Cellular Towers in Developing Nations are Making the Move to Solar Power*.

[142] Naikodi, *Solar-Wind Hybrid Power for Rural Indian Cell Sites*, 69–72.

round as extending the power grid to these locations are cost prohibitive. As the price of diesel, regular maintenance, fuel delivery, and pollution from generators cause cell sites to become nonprofitable, India's government, who subsidizes diesel fuel, set aggressive standards to lower their fossil fuel dependence.[143] The Indian government has mandated that by 2015, 50 percent of its rural cell sites be converted to operate on renewable energy.[144] An article produced by Dr. Allabaksh Naikodi proposes how the use of renewable energy can reduce the consumption of diesel and potentially allow BSs complete independence from grid power.

Dr. Allabaksh Naikodi conducted a study published 2010 in the *Institute of Electrical and Electronics Engineers (IEEE)* on the use of alternative energy to provide sustainable power to base stations in remote locations of India.[145] The study provided valuable insight regarding lowering the overall consumption of diesel fuel by using abundant renewable solar-wind energy.

The study first analyzed electronic components required to operate a BS along with the related power consumption. In doing so, the average power utilization was derived, which ranged from 3.04–6.32 kilowatt (kW), respectively. Air conditioning was identified as the main power consumer—requiring 60 percent of overall power for in-door sites. Second, alternative solar and wind energy were independently tested to determine the optimal combination to produce the required electrical load needed to power a BS. Last, the study analyzed an average GSM type BS deployed in a rural location with a 2.8 kW peak power requirement for a period of five months. Dr. Naikodi then retrofitted the BS with renewable energy and monitored its performance for an additional five months. Eighteen photovoltaic solar panels were installed producing 4.05kW with wind turbine producing 3kW. The energy produced from the hybrid solar-wind installation was subsequently stored in a battery bank, accessible to a load controller that efficiently cycled between renewable energy, a diesel generator, and grid power to keep the BS operating.

143 Naikodi, *Solar-Wind Hybrid Power for Rural Indian Cell Sites*, 69–72.

144 Tweed, *Why Cellular Towers in Developing Nations are Making the Move to Solar Power*.

145 Naikodi, *Solar-Wind Hybrid Power for Rural Indian Cell Sites*, 69–72.

The study effectively proved how efficient and cost effective renewable energy can be for powering base stations in remote locations and the implication for broader usage. To illustrate the savings produced utilizing renewables, the study calculated the annual cost of powering a base station with a diesel generator. There are approximately 110,000 rural cell sites—each site consumes on average 1000 liters or 264 gallons of diesel per month. The cost to power a single BS per year equates to $12,257, with the price of diesel at $3.869 per gallon in the U.S. That figure translates to $1.3 billion per year when the 110,000 rural sites are summed.[146] The results of installing solar-wind renewable energy produced a 90 percent reduction in diesel usage. The monetary and environment factor of using less diesel fuel is astonishing. The following explanation of fuel cells illustrates how incorporating such technology can further lower the dependency of diesel generators.

D. ALTERNATIVE ENERGY, FUEL CELLS

Fuel cells are an environmentally friendly technology that has seen expansive application in the public and private sector, capable of powering small stationary components to entire buildings without the production of harmful green house gases.[147] They are capable of remote monitoring and operation allowing them great flexibility in reducing power consumption on the grid by switching a large distribution of them on at peak demand times. There are several types of fuel cells, however, the most common utilized for small to medium standby power is proton exchange membrane (PEM).[148] Fuel cells combine a fuel source such as (hydrogen, natural gas, methane, methanol) with oxygen to produce electricity through a chemical process.[149] The process occurs absent any moving parts or combustion.[150] Water and heat are the only effluents expelled from

146 Price reflected from U.S. Energy Information Administration, http://www.eia.gov/petroleum/gasdiesel/.

147 “When the Grid Fails: Fuel Cells Power Critical Infrastructure in Disasters.”

148 Blanchard, “Smart Energy Solutions using Fuel Cells,” 2011, 2.

149 Ibid.

150 See fuelcells2000 for further explanation, http://www.fuelcells.org/base.cgim?template=types_of_fuel_cells.

the process.[151] They are structurally similar to a battery utilizing and electrolyte. However, they do not store electricity nor run down or require recharging.[152]

Recognizing the inherent dependency and vulnerability of grid power, fuel cells become a viable component in providing uninterrupted operational capacity for telecom providers. For instance in 2008, Sprint Nextel began a pilot program sponsored by the Department of Energy through its American Recovery and Reinvestment Act (ARRA) to promote alternative energy; installing fuel cells for back-up power in a portion of its BSs.[153] The company has since advocated the complete replacement of all its existing back-up power equipment at telecommunications sites with fuel cells.[154] Several other wireless service providers have also pursued installing fuel cells to BSs. MetroPCS being one of the largest deploying 2,000 in California, and 350 in South Florida.[155]

Recent natural disasters have tested the resilience of fuel cells. Superstorm Sandy (2012) pounded the Bahamas, leaving several islands without power. On the islands of New Providence, Abaco, and Grand Bahama, fuel cells kept the cellular network functioning for seven days, allowing critical communications.[156] The cost benefit of utilizing fuel cells is starting to rival diesel generators, which are still the primary component to provide backup power. Fuel cell manufacture Ballard Power Systems claims their ElectraGen-H2 fuel cell provides greater efficiencies than conventional diesel generators with a return on investment projected over three years when tax credits and maintenance savings are factored in.[157] Within the mobile telecom industry, fuel cells have shown value in two major areas, 1) UPS/backup capacity during grid failure, 2) Power to remote locations where grid power has not or will not be delivered. With the

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152 Maya Smart, “Hydrogen Fuel Cells Backup Infrastructure Cleanly and Quietly,” Department of Energy, http://energy.gov/articles/hydrogen-fuel-cells-backup-infrastructure-cleanly-and-quietly.

152 “When the Grid Fails: Fuel Cells Power Critical Infrastructure in Disasters, 2.

153 Kevin Fitchard, *THE GREENING OF XOHM*, 3844–0.

154 “When the Grid Fails: Fuel Cells Power Critical Infrastructure in Disasters.”

155 Ibid.

156 Ibid.

157 Ibid., 5.

second option, a hybrid combination of photovoltaic (PV) solar panels, with battery banks offers optimal reliability and autonomy from grid power.[158]

India has taken the lead globally in leveraging renewable and alternative energy to power their cellular network. The aforementioned local research and development conducted by Dr. Naikodi, along with industry reports, support a national effort to lower fossil fuel dependence. Telecom service providers in India have accepted this environmentally supportive policy as illustrated in their overall cellular network transformation, converting one city at a time. The aggressive time frame and commitment should also be noted as the "Green City" initiative was conceptualized in early 2011.[159] The world's largest telecom tower company, Indus Towers Limited, through its national Carbon Abatement Program has converted cell towers in over six cities in India to utilize alternative energy. Mumbai has been rebranded as a "Green City," supporting the company's commitment to the environment.[160] The company's CEO B. S. Shantharaju elaborates on the company's vision; "We will take this campaign to as many cities as possible and recreate the image of our country as a Green Nation."[161]

158 Pereira-Bahia and Paulmier, "Operational Feed-Back on Fuel Cell Solutions for Telecom Needs," 2007.

159 "Indus Towers' Sites Turn Green in Mumbai."

160 Ibid.

161 Ibid.

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VI. INDIA’S MOBILE TELECOMMUNICATION STRATEGY: A MODEL FOR U.S. CONSIDERATION

A. INTRODUCTION

India’s NTP strategy is a culmination of the nation’s commitment to achieving economic superiority through technological advancements in mobile cellular infrastructure. There is also a parallel effort to provide socio-economic parity to its under serviced majority population with equal emphasis on environmental consciousness. The Indian government recognizes the role mobile commerce plays in the nation’s future economic prosperity. The strategic direction taken within this policy demonstrates how government sponsored initiatives supported by private industry can achieve great things for the populous. There are four main strategies targeted within the NTP that have direct implications for U.S. application: 1) Expanding its commercial mobile wireless network to rural underdeveloped regions with inadequate grid power, 2) Creating a robust resilient mobile wireless network capable of withstanding disasters both natural and manmade, 3) Incentives for corporate adoption, and 4) Investing in renewable/alternative energy to power base stations in order to lower fossil fuel dependency and harmful carbon emissions.

B. BACKGROUND

There are noteworthy perspectives, guiding India to purse such an ambitious policy for their commercial mobile network. First, they recognized the value and trajectory of mobility and the associated m-commerce that can be realized. Mobile phone calls attributed for 911 million out of the 943 million total calls respectively at the end of February 2012. In order to tap into this vast market with infinite potential, the country requires reliable cellular phone service. However, a major impediment in achieving this goal is overcoming an unreliable and underdeveloped power grid.

India’s commercial power grid is highly unstable providing power for mere hours in certain locations. The grid is also concentrated in Metropolitan cities and does not extend to the majority of rural areas, where the largest portion of the population lives.

This becomes a core perspective in the NTP, which proposes to "transform the socio-economic scenario through accelerated equitable and inclusive economic growth by laying special emphasis on providing affordable and quality telecommunications services to rural remote areas."[162] These rural areas offer a tremendous under-penetrated market, which the government projects will be an exponential driving force once exposed to mobile resources. The strategy takes into consideration the enormous cost associated with physically extending the power grid to distant remote areas and notes these communities may be better served by erecting self-sustainable BSs. BSs in the rural areas lacking grid power would be constructed to use renewable/alternative energy as the primary power source.

Within the core strategy of the NTP is mitigating the harmful practice of utilizing diesel generators to power BSs during grid failure. The obvious drawbacks of generators are; regular maintenance, consistent fuel delivery, carbon emissions, and consuming large quantities of diesel fuel. As noted earlier within this paper, India does not produce the majority of its fossil fuel and relies heavily on imports. This dependency is a primary factor in developing self-sustainable BSs, as fuel costs are projected to continue rising globally.[163] With the fall of the Soviet Union, India no longer has the political relationship to rely on cheap imports.

In order to stimulate investment and commitment towards the enormous changes perceived in this strategy, the Indian government framed the policy to be conducive towards corporate adoption. It outlines the need for financial and fiscal incentives to draw local manufacturing of telecom products along with encouraging research and development.[164] The NTP further proposed the country invest in renewable and alternative energy to decouple its fossil fuel dependency. There is a concerted strategic effort to achieve this. It proposes the "adoption of green policy in telecom and incentivize use of renewable energy sources for sustainability." This is a crucial factor in moving

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162 *India's National Telecom Policy - 2012*.

163 Tammy Parker, "Vendors and Operators Target a Greener LTE Future," http://www.fiercewireless.com/tech/story/vendors-and-operators-target-greener-lte-future/20130–12–3.

164 *India's National Telecom Policy - 2012*, 7.

towards an eco-friendly self-sustainable mobile network by providing economic incentives. The second portion of this strategy targets the use of energy efficient equipment. The overall goal is to lower the energy consumption to levels where renewable energy is better suited to power the entire system. India has set an aggressive goal of converting 50 percent of its rural base stations to operate on renewables by 2015.[165] This is no simple task considering the nation has approximately 400,000 BSs. Phase two of this strategy target 75 percent of rural, and 33 percent of urban BSs by 2020 to utilize renewables.

C. DISCUSSION

The strategic direction taken by the Indian government to modernize its mobile cellular network was born from necessity. However, it developed into a nationwide narrative with enormous potential for supporting the country's economic prosperity. The core focus envisions how to create a cellular network with the capacity for resilience, powered by renewable/alternative energy, able to provide services to the majority-underserviced population. In order to create a robust cellular network, the NTP targets the deficiencies of its current infrastructure and identifies potential solutions to rectify. For instance, how renewables can offset the irregular service provided by the power grid. As such, the country recognizes the interdependence of the private sector to stimulate some of these changes proactively, along with the limitations of its power grid to provide reliable service. Thus, lending to incentives for corporate adoption. The policy speculates how these changes would offer greater services to its majority population, which in turn would contribute to the economic vitality of the country via an increase in mobile commerce generated through a modern cellular network.

D. U.S. IMPLICATIONS

Given the recent litany of natural disasters, all of which exposing various vulnerabilities within the U.S. commercial mobile network, India's NTP-2012 provides a potential framework to achieve a resilient environmentally sustainable mobile network.

165 Tweed, *Why Cellular Towers in Developing Nations are Making the Move to Solar Power*.

However, U.S. telecom service providers would have a critical role in the success of theses policy changes and represent a major hurdle to overcome. In order to move forward with many of these changes, a cost-benefit model would need to be constructed to demonstrate actual return on investment from upgrading the commercial cellular network. Some carriers may offer resistance, simply because the U.S. has a power grid that is highly reliable, with the loss of revenue from inoperable BSs minimized due to infrequency. Mobile carries have also shown a reluctance to install back-up power to BSs, as seen in the repeal of legislation post-Hurricane Katrina, which mandated 8 hours of continued service during power outages.[166] In addition, renewable/alternative energy requires substantial initial investment.

These issues are relevant and require a collaborative effort between the government and private industry. However, this should not detract from the key strategic goals presented within the NTP, which can be implemented now with the appropriate support. Timing is opportune as FirstNet undertakes a national review of the U.S. commercial mobile cellular network to determine the implications for supporting the NPSBN. The driving force behind India's strategic telecom policy assumed the negative implications of supporting national economic and social growth with a substandard electrical grid. Consequently, the principal strategic components limit that exposure by decoupling their mobile telecom network from the electric grid through the use of renewable energy with the realization that harmful carbon emissions would also decrease.

Another significant assumption is reducing India's overall consumption of imported crude oil. U.S. telecom service providers have not considered this an issue potentially because of America's reliable power grid. Thus, lowering the need for mass distribution and use of diesel generators throughout the network for everyday use. India crafted the NTP based on a vision to provide mobile wireless access across the country, which is estimated to provide substantial economic stimulus via m-commerce, while limiting the exposure of a faulty power grid. Applying this strategy to the U.S. cellular

[166] "When the Grid Fails: Fuel Cells Power Critical Infrastructure in Disasters."

network is challenging but should not discount the fact that the proposal provides vast improvements in resilience to a network that has systematically failed during power outages and natural disasters.

FirstNet is positioned to facilitate some of these changes with the help of the FCC and the U.S Department of Energy. The U.S. cellular network's lack of resilience creates a challenge and opportunity for FirstNet. FirstNet is sanctioned to create a robust resilient NPSBN that will operate on 4G-LTE technologies capable of operating during critical events and disasters. There are three ways for FirstNet to achieve this: 1) Construct an entirely independent and new cellular network, 2) Leverage the current commercial cellular network, or 3) Create a hybrid network, utilizing commercial and newly constructed BSs to supplement areas with poor commercial coverage.

The major telecom service providers have already adopted the primary technological driver the NPSBN will operate over 4G-LTE, as the next generation technology networks will migrate too. This provides an enormous opportunity as they engage in converting old equipment in BSs to new 4G-LTE energy efficient technologies that consume significantly less power. Telecoms can incorporate renewable/alternative energy during this upgrade. If an agreed upon portion of the U.S. cellular network can be retrofitted with renewable and alternative energy capable of providing coverage during power outages suitable to FirstNet's standard for reliability, why would they need to construct an independent network? The cost implications and ease of deploying the NPSBN would save years and billions, if the primary U.S. commercial cellular network could be hardened, and renewable energy can provide that resilience.

This issue needs to be brought to the forefront of the discussion as the NPSBN moves well beyond the conceptual stage and into the early stages of planning its build out. Strategically it should follow: 1) Standardized construction codes to identify where BSs can be built and to relocate those that are in high risk areas, 2) Minimum energy efficiency guidelines for required components, 3) Renewable and alternative energy requirements capable of providing self-sustainability, and 4) Pollution restriction

standards eliminating the use of diesel generators. As FirstNet develops various requests for information/proposals, these underlying requirements should be clearly outlined as a component of any proposal.

Finally, the technological shift to high-speed digital networks, although logically diversified, relies on the same core infrastructure—fiber optic cable. The complexity of convergent telecom networks capable of transmitting rich multi-media, data, and voice all over a single medium at the speed of light, creates a potential risk through optimization. As we increase capacity and marvel at such progress, we discount self-organization that is an inherent consequence. The national campaign pursued by telecom providers to decommission conventional copper telephone service eliminates a vital mode of communications that has immense value during power outages, as many have come to rely on. In order to counter this self-organization, these networks require decoupling, hence, providing redundancies via different mediums, potentially provided by renewable/alternative energy, and the already established legacy copper phone lines.

VII. CONCLUSIONS AND RECOMMENDATIONS

The government has begun to realize the need to change how critical infrastructure is designed and functions in the U.S. The NYS 2100 Commission, a document critiquing the impact of Superstorm Sandy, identifies the critical dependency a centralized power grid has and determined transitioning to micro grids would provide greater resilience by limiting the degree of failure that can cascade throughout an entire network. In addition, renewable/alternative energy plays an integral part in providing continuity of services during power outages. The document proposed the use of incentives to stimulate investment in renewables, to decouple grid power dependency, while supporting the Regional Greenhouse Gas Initiative of lowering carbon emissions. Such proposals foster the appropriate atmosphere to advocate hardening BSs with renewable/alternative energy.

There has been a parallel effort to increase the use of alternative energy taken on by the U.S. Department of Energy. The Department of Energy has provided subsidies for companies investing in alternative fuel cell technology in order to increase usage. Sprint Nextel, was among one of the first participants of this program testing fuel cells in their WiMAX network.[167] The company, in a nascent stage in 2008, explored the viability of creating a "green network," illustrating how American telecom service providers are not adverse to economically and environmentally sustainable mobile networks. However, such efforts have not risen to a level of urgency, for a myriad of reasons. Some of which can be attributed to the difficulty in changing local zoning ordinances along with educating the public on the use of alternative energy, which were still in early product design stages in 2008. The Environmental Protection Agency can play a pivotal supporting role with an information campaign about the benefit and safety of alternative energy.[168]

167 Fitchard, *The Greening of XOHM*, 38–40.

168 Ibid.

In order to achieve a resilient green commercial cellular network, there are key incremental steps that need to be addressed; 1) Elevating minimum standards of operational capacity (e.g., how long must BSs operate after power failure), 2) Codification of law for BSs to provide continuous service during power outages using renewable/alternative energy, 3) Ordinance changes to account for standard construction practices (e.g., erecting BSs outside of flood zones), and 4) Finally, incorporating energy efficient technology that lowers overall power consumption for BSs. The F.C.C would need to propose minimum extended operational capacity for BSs when power failure occurs. From a disaster management perspective, maximum operational time would be preferred, however, there should not be a financial burden to arrive at this end state. Initial requirements should allow BSs to function for five days once grid power fails. That figure should increase over the next three years to complete self-sustainable BSs no longer requiring a connection to the power grid.

BSs should not immediately fail when grid power is lost. There should be controlled failure that occurs incrementally, where a self-sustainable back-up power design allows continuous operations throughout various stages in a disaster when power is lost. The research produced by Dr. Allabaksh Naikodi offers a suitable model for U.S. deployment. Within Naikodi's logical flow, solar photovoltaic panels combined with wind turbines create the first layer of power. Battery banks receive charge from solar panels and wind turbines, which are subsequently switched on when primary solar-wind power is unavailable. A deviation from his model incorporates fuel cells as the next layer of redundancy—activating when battery banks run low from potential environmental factors prohibiting full charging capacity of solar wind. Within Naikodi's model, this layer would have utilized a diesel generator, although minimally as his test results demonstrated. The fuel cell supplemental is to achieve a completely carbon emission free BS.

Prior to implementing alternative/renewable energy in the mobile telecom sector, the federal government needs to first, direct the FCC to mandate standardized construction practices for the locations of BSs. They should be constructed outside of flood prone areas to mitigate the impact from storm surges. Second, telecom service

providers upgrading their cellular network to support 4G-LTE can incorporate alternative and renewable energy as backup/primary power for BSs during this lengthy transition. Third, a moratorium on the use of grid power for future constructed BSs and decommissioning copper landlines should be enacted. Last, a predetermined time period (to be developed by the FCC) allowing cellular carriers to convert 50 percent of their BSs to alternative/renewables, with incentives for greater conversion. This is an ambitious goal considering the U.S. has less than one percent of its BSs equipped with back-up power provided by renewable/alternative energy, but yet attainable.[169]

A. GREEN BASE STATION CONVERSION-LOCAL PILOT

Conceptually applying a national strategy to develop resilient green BSs to an individual city provides a framework, which can be replicated throughout the country. The following pilot demonstrates the steps needed to harden BSs for a local city/county. The first step requires accounting for all BSs within a specific city. This should already be available and provided by the local telecom provider. Next, a map of the city with an overlay of flood zones should be utilized for plotting BS locations. This will determine priority order in either retrofitting or relocating BSs. Generally, costal areas receive the most damage from these storms and should be the first addressed. Second, an assessment of BSs constructed in flood zones—noting, if they were affected by prior storms or are at risk for future damage. Third, the survey should continue with the assistance of the local telecom provider in determining what form of back-up power is installed, if any, and to which specific towers. Derecho has shown that service providers are not proactively documenting this.[170]

Once the initial assessment is completed, a project plan can then be formalized. There are two ways to consider moving forward. First, with legislative approval requiring BSs to operate during power outages and incorporating renewable and alternative energy.

169 Tweed, *Why Cellular Towers in Developing Nations are Making the Move to Solar Power*.

170 A Report of The Public Safety and Homeland Security Bureau, *Impact of the June 2012 Derecho on Communications Network and Services. Report and Recommendations*.

Second, without legislative approval but carried out under voluntary compliance from telecom service providers. The following requirements will need to be gathered prior to initiating construction.

1. Determine which BSs would be retrofitted with renewable/alternative energy.

2. Determine which BSs require relocation due to improper site selection (e.g., flood zones).

3. Determine appropriate suppliers of equipment and develop timetable to insure production and delivery of supplies do not impact onsite work.

After completing above assessment, the time line for the necessary work can then be defined. The process should be staged accordingly with appropriate milestones to track progress. The city should be broken down into sectors with priority given to coastal/flood prone areas. These areas would be the first retrofitted, as they are most at risk.

At this point, telecom service providers are given the directive to complete retrofitting and relocating BSs to areas protected from flood or surge damage. The process should mandate completing high priority areas within two years. After which, a minimum of fifty percent systematic conversion of the remaining sectors to renewable/alternative energy should follow over the next five years. The researcher proposed this time frame taking into consideration that India will reach this milestone with a cellular network greater in size at 400,000—100,000 more BSs than the U.S.[171] Tweed notes that the Indian government has mandated 50 percent of rural BSs to be powered by renewables by 2015.[172] To facilitate early compliance, incentives become important and should be given to telecoms to encourage further conversion. Arriving at this level of resilience within five years is a reasonable time line considering less than one percent of BSs in the U.S. is powered by renewables.[173]

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171 The U.S. cellular network is comprised of approximately 300,000 BSs, "Wireless Quick Facts." Comparison taken from December 2007 to December 2012.

172 Tweed, *Why Cellular Towers in Developing Nations are Making the Move to Solar Power*.

173 Ibid.

B. CONCLUSION

In summary, it is integral to answer the core purpose of this research. Are there common reasons cellular base stations fail? An analysis of Hurricane Katrina, Superstorm Sandy, and Derecho, depicts common causes for failure. Primarily, BSs failure can be attributed to the loss of grid power. Once the power grid fails, BSs either operate on battery power for a few hours or diesel generators, if so equipped. For those units equipped with diesel generators, fuel starvation or mechanical failure was the main culprit for failure. Additionally, the location of cell sites constructed in flood zones experienced a greater degree of physical damage from storm surge as compared to high wind. The issues discovered do not pose a severe impediment for overall remediation. Enacting standard construction regulations would alleviate damage to BSs constructed in flood zones ensuring they are located out of harms way. The researcher could not locate any such ordinances regulating where BS could or could not be constructed. Further, failures that occurred from a loss of grid power can be supplanted by incorporating resilient back-up power provide by solar-wind, and fuel cells that are not impacted in the event of a fuel shortage. Additionally, the investment into micro grids would also decrease the cascading effect from centralized grid failure.

The researcher then analyzed if the strategic direction taken by the Indian government to increase resilience within the country’s mobile cellular network utilizing renewable energy were considered a viable policy option for the United States to pursue? The main directives within the NTP offer practical application for the U.S. government to consider. The core focus bears direct relation with transitioning away from cost prohibitive and environmentally impactful fossil fuel dependent cellular network. The document envisions reaching its rural parts of the country by constructing BSs powered with renewable/alternative energy to provide essential services and opportunities to these isolated communities. Through the NTP, the government saw tremendous potential in using cellular technology to reach the vast majority population, 68 percent who live in these distant rural areas. The economic prospects of tapping into an under utilized core demographic offers significant financial benefit derived from the ever increasing role of

mobile commerce. The framework of the NTP can be implemented in the U.S. from an overall policy perspective under the direction of the FCC

The research also analyzed if implementing such a policy would allow BSs to provide continuous service during power failures. The implication of using the NTP strategy would allow BSs to provide continuous service during power failures in addition to supporting the RGGI. In order to provide continuous service during power failures, BSs need a supplemental power source provided by some form of back-up power. Installing renewable/alternative energy would provide BSs with the ability to continue functioning during power outages. Also, the failure rate and maintenance cycle for currently used generators would be eliminated, if renewables were installed. Second, the critical dependency of logistically coordinating fuel to these sites would also be removed. Retrofitting BSs with renewable energy, as tested by Dr. Allabaksh Naikodi, lowered dependency on diesel to marginal levels. Incorporating fuel cells in place of generators removed the diesel dependency and eliminated any carbon emissions.

In addition, can the use of alternative and renewable energy provide BSs with the capacity to be self-sustainable, no longer reliant on grid power? The researcher determined using alternative and renewable energy provided BSs with the capacity to be self-sustainable, no longer reliant on grid power. The main premise within the NTP is to increase resilience of India's mobile cellular network, specifically to remote areas by erecting self-sustainable BSs. The document further expands on designing BSs to use econ-friendly equipment with lower power consumption allowing renewable/alternative energy the ability to be an optimal solution to power BSs without the need for grid power. This model can be implemented in the U.S. to systematically lower the overall power consumption for these cellular networks—freeing energy to be redistributed throughout the power grid.

Finally, how will these changes affect the construction of the NPSBN? As the NPSBN transition from concept to construction, the infrastructure essential to make this network a viable option—the commercial cellular network—fails to provide the public and first responders a reliable source of communicating during power outages. The changes proposed within the NTP would positively support the NPSBN. The main focus

of the NTP of leveraging technology to provide BSs with the independence to operate without grid power is exactly what is needed to harden the U.S. cellular network to provide mission critical capacity to first responders. *Linda K. Moore*, *Public Safety Communications and Spectrum, Resources: Policy Issues for Congress* comments on the potential deficiencies in the U.S. commercial cellular network; "Infrastructure for vital services such as emergency communications requires additional measures to ensure operability in difficult environments such as extreme weather and power failures." Additionally, Moore reiterates that cellular BSs need to be "strengthened against natural hazards and furnished with back-up power supplies that can outlast extended power outages."[174] The NPSBN will operate over, 4G-LTE cellular technologies; the standard service providers throughout the U.S. are currently migrating too. The dilemma for FirstNet to consider is should they construct an entirely separate network or leverage some or the entire commercial wireless network. In order to deploy the NPSBN within a reasonable timeframe with significantly lowered cost, FirstNet needs to leverage the commercial cellular network. New BSs should only be constructed to supplement coverage, not to replace it, keeping the cost of infrastructure down.[175] If this strategy is considered, it becomes essential that the suggestions made within this thesis for creating resilient BSs be the minimum standard incorporated by service providers. Without incorporating these changes, the cellular network will not be able to support first responders in mission critical situations, when power is lost.

Finally, those reluctant to utilize the commercial cellular network for the NPSBN can reference the occurrences that transpired on September 16, 2013, where an active shooter killed 12 and wounded four at the Washington Navy Yard mass shooting. During the incident, first responder's encountered communication difficulties when their portable radios, which receive signal from radio towers dedicated solely for fire and police failed to provide adequate coverage.[176] As the chaos unfolded, cell phones were ultimately

174 Moore, *Public Safety Communications and Spectrum Resources: Policy Issues for Congress*.

175 James Arden Barnett Jr., "Subcommittee on Communications and Technology Committee on Energy and Commerce US House of Representatives Hearing on "Oversight of FirstNet and Emergency Communications" March 14, 2013."

176 Bogardus, *Radios Failed during Navy Yard Attack, Emergency Responders Say*.

relied on to coordinate the response and recovery efforts when police and fire radios became unreliable. This shows the essential role the commercial cellular network plays in coverage and capacity—providing this critical level of communication for incident management. The incident demonstrated how current mobile cellular infrastructure provided vital communications for first responders, while highlighting two significant issues debated since the 9/11 Commission recommendations. First, the incident illustrates how there is still a major problem with first responders from various agencies and jurisdictions communicating among each other at an emergency incident. Second, the limitations of radio systems dedicated for police and fire could not provide adequate coverage, leading to communications black out as noted by the incident commander who was unable to communicate from his position inside the building to fire units outside of the building.[177]

There are various examples referenced within this research that provide alternatives to create a resilient mobile cellular network capable of functioning independent of grid power. They are not without cost or challenge; however, they do offer an encouraging opportunity for environmental security, operational functionality, and sustainable energy. Utilizing a hybrid combination of fuel cells with solar-wind power is a step in the right direction, with the terminal objective of eliminating reliance on diesel generators.

Base stations' operating solely on renewable energy is an achievable goal as the proliferation of energy efficient components and technologies are leveraged in their design. Creating these various layers of autonomy from grid power offers greater resilience for a public that fails to realize the ramifications of an all-cellular phone network—while ensuring the future survivability of a soon to be constructed NPSBN. These options should be reviewed by the N.T.I.A, FCC, FirstNet, and then presented to wireless industry leaders as a means to introduce dialogue to strengthen current wireless infrastructure. It should also provide context to reconsider decommissioning vital copper landlines. The practices and strategy taken by phone carriers in the U.S. addresses

[177] Bogardus, *Radios Failed during Navy Yard Attack, Emergency Responders Say*.

primarily profit, but at the expense of public safety. Standing up a high-speed wireless network is a marvel that will offer great value and support an insatiable global appetite for mobile commerce. However, it should not be done without thoroughly appreciating the unintended consequences, which may potentially be catastrophic.

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